THE UNIVERSITY
OF MICHIGAN
MAR 25 1960
ENGINEERING
LIBRARY

Journal

of

THE ROYAL AERONAUTICAL SOCIETY

FEBRUARY 1960

CONTENTS

NOTICES

SOME DEVELOPMENTS IN BOUNDARY LAYER RESEARCH IN THE PAST THIRTY YEARS—THE THIRD LANCHESTER MEMORIAL LECTURE — Professor Dr. H. Schlichting

THE LANDING GEAR OF THE SC. 1 AIRCRAFT — H. G. Conway

AGRICULTURAL AVIATION — Air Commodore A. H. Wheeler

AERIAL OPERATIONS PLANNING IN THE UNITED KINGDOM — Peter J. W. King

TECHNICAL NOTES

Solar Probes—S. W. Greenwood. High Speed Flow Through Perforated Plates—P. G. Morgan. The Buckling of a Circular Plate with a Concentric Circular Hot-Spot—K. I. Mckenzie. Operational Problems of Take-Off and Landing: *A Correction to p. 695, December 1959*—A. P. W. Cane.

GRADUATES' AND STUDENTS' SECTION

THE BRANCHES

THE LIBRARY REVIEWS REPORTS

TWELVE SHILLINGS AND SIXPENCE MONTHLY

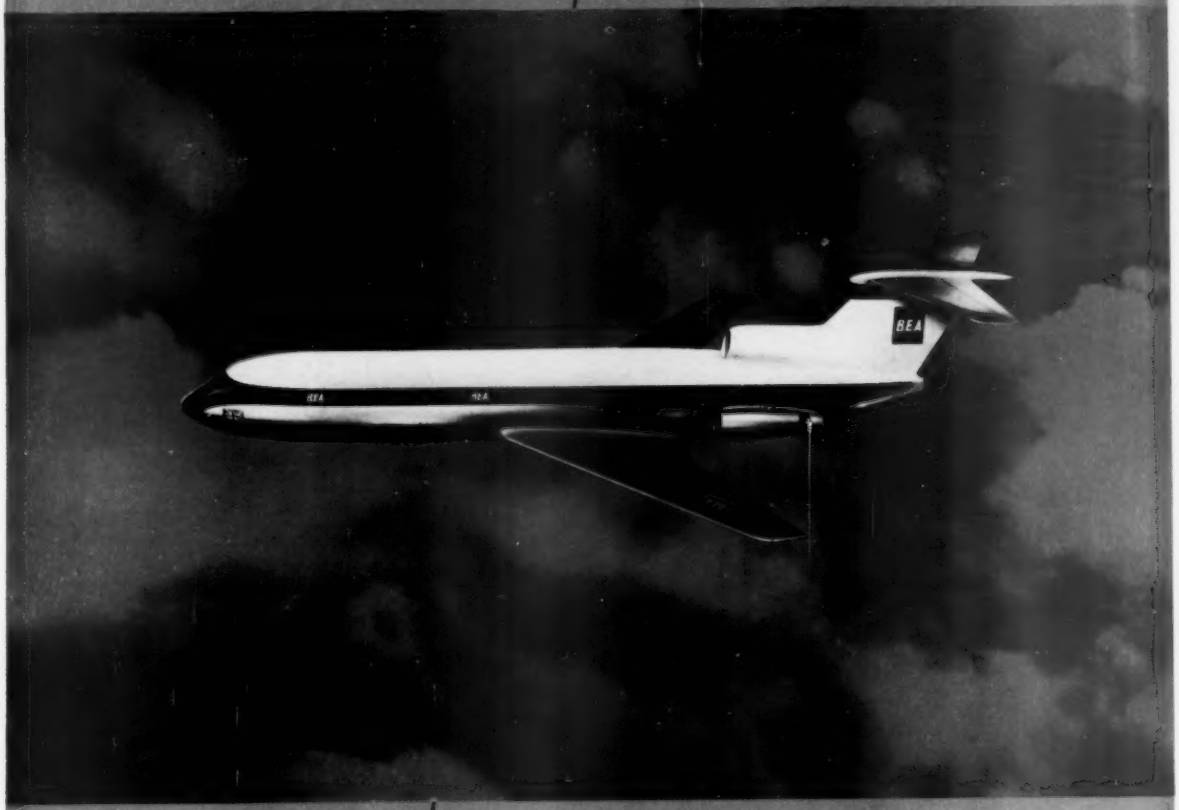
LONDON

4 HAMILTON PLACE W1

HOBSON CONSTANT SPEED ALTERNATOR DRIVES

are now specified for the

AIRCO D.H. 121 JET AIRLINER



The outstanding advantages inherent in this ingenious design further exemplify the Company's aim in keeping pace with progress.

In this aircraft, described as the ultimate in subsonic speed combined with the best possible operating economy, the entire electrical generating capacity is dependent upon its constant speed drives, so that reliability and a long life between overhauls are of vital importance. Designed specifically for civil aircraft duties, HOBSON Constant Speed Alternator Drives achieve these essential qualities by their novel construction permitting the use of a transmission oil pressure of only 500 p.s.i. In addition, a unique pump off-loading system reduces the pump transmission pressure to 50 p.s.i. when the aircraft is cruising.

H · M **Hobson** *LIMITED · FORDHOUSES · WOLVERHAMPTON*

Journal of

THE ROYAL AERONAUTICAL SOCIETY

IN WHICH ARE INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS
AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

PUBLISHED MONTHLY AT

4 HAMILTON PLACE, LONDON, W.1

Telephone: Grosvenor 3515-9 *Telegrams:* Didaskalos, Audley, London

SUBSCRIPTIONS: £7 10s. 0d. PER ANNUM, PLUS 9s. POSTAGE AND PACKING
SINGLE COPIES: 12s. 6d. PLUS 9d. POSTAGE AND PACKING

VOLUME 64 FEBRUARY 1960 NUMBER 590

CONTENTS

PAGE

Notices VII

The Burnham Committee—The New By-Laws—All-Day Symposium on Vehicle and Instrumentation Problems in Upper Atmosphere Research—New Year's Honours List—Foreign Honorary Fellows of the I.A.S.—National Council for Technological Awards—The British Rocket Programme—Thirteenth Louis Blériot Lecture—Ties—Dinner of the Past Presidents of the Society—An Apology—Diary—Elections—Supplement to Oxford English Dictionary—News of Members—Summaries of Lectures—Lecture Theatre Appeal—Man Powered Aircraft: Regulations for the Kremer Competition.

Some Developments in Boundary Layer Research in the Past Thirty Years—The Third Lanchester Memorial Lecture
PROFESSOR DR. H. SCHLICHTING 63

The Landing Gear of the SC. 1 Aircraft H. G. CONWAY 81

Agricultural Aviation Group

Agricultural Aviation AIR COMMODORE A. H. WHEELER 87

Aerial Operations Planning in the United Kingdom PETER J. W. KING 93

Technical Notes 102

Solar Probes—S. W. GREENWOOD. High Speed Flow Through Perforated Plates—P. G. MORGAN. The Buckling of a Circular Plate with a Concentric Circular Hot-Spot—K. I. MCKENZIE. Operational Problems of Take-Off and Landing: **A Correction to p. 695, December 1959**—A. P. W. CANE.

Graduates' and Students' Section 107

Branches Page 108

The Library 109

REVIEWS: Aircraft and Missiles—Dictionary of Aeronautical Engineering—Fuels and Lubricants—Internal Stresses and Fatigue in Metals—Desert Squadron.

ADDITIONS TO THE LIBRARY. REPORTS.

All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

ADVERTISEMENT OFFICE: *One Arundel Street, Strand, London, W.C.2 Covent Garden* 1612.

PRINTED BY THE LEWES PRESS, WIGHTMAN & CO. LTD., LEWES, SUSSEX, ENGLAND, AND PUBLISHED BY THE ROYAL AERONAUTICAL SOCIETY, 4 HAMILTON PLACE, LONDON, W.1, ENGLAND

THE ROYAL AERONAUTICAL SOCIETY

Overseas Divisions

AUSTRALIA
President: M. M. WAGHORN, A.F.R.Ae.S.
Hon. Secretary: W. ISBISTER, [A.F.R.Ae.S.
Science House, Gloucester & Essex Streets, Sydney, New South Wales.
Branches at: Sydney, Melbourne, Adelaide.

NEW ZEALAND
President: D. A. PATTERSON, M.B.E., A.R.Ae.S.
Hon. Secretary: T. T. N. COLERIDGE, [A.F.R.Ae.S.
The Shell Company of New Zealand Ltd., Box 2091, Wellington.
Branches at: Auckland, Wellington. Palmerston North, Christchurch.

SOUTHERN AFRICA
President: COLONEL J. D. T. LOUW, A.F.R.Ae.S.
Hon. Secretary: Mrs. D. D. HUGHES, 14 Keyes Court, Keyes Avenue, Rosebank, Johannesburg.
Branches at: Durban and Salisbury.

Overseas Branch

SINGAPORE *President*: Air Marshal THE EARL OF BANDON, K.B.E., C.B., C.V.O., D.S.O., R.A.F.
Chairman: E. A. CRABBE, A.F.R.Ae.S.
Hon. Secretary: T. C. CHIOLE, A.R.Ae.S., c/o Malayan Airways, Paya Lebar Airport, Singapore.

Branches in the United Kingdom

BELFAST
President: Rear-Admiral Sir MATTHEW S. SLATTERY, C.B., F.R.Ae.S.
Chairman: H. G. PARKER, A.F.R.Ae.S.
Hon. Secretary: D. F. DYSON, A.R.Ae.S., Short Brothers & Harland Ltd., Belfast.

BIRMINGHAM AND WOLVERHAMPTON
President: L. S. GREENLAND, F.R.Ae.S.
Chairman: H. BOTTOMS.
Hon. Secretary: A. JAMES, A.F.R.Ae.S., Sir W. G. Armstrong Whitworth Aircraft Ltd., Warwick Chambers, 14-20 Corporation Street, Birmingham 2.

BOSCOMBE DOWN
President: Air Cdre. A. E. CLOUSTON, C.B., D.S.O., D.F.C., A.F.C.
Chairman: Dr. D. CAMERON, F.R.Ae.S.
Hon. Secretary: G. F. LANGDON, Grad.R.Ae.S., A. & A.E.E., Boscombe Down, Amesbury, Wilts.

BRISTOL
President: PROFESSOR A. R. COLLAR, F.R.Ae.S.
Chairman: H. GIDDINGS, F.R.Ae.S.
Hon. Secretary: G. WANSBROUGH-WHITE, A.R.Ae.S., Bristol Aircraft Ltd., Filton, Bristol.

BROUGH
President: N. E. ROWE, C.B.E., F.R.Ae.S.
Chairman: B. P. LAIGHT, F.R.Ae.S.
Hon. Secretary: A. D. HOWARTH, A.R.Ae.S., Blackburn Aircraft Ltd., Brough.

CAMBRIDGE
President: Professor W. A. MAIR, F.R.Ae.S.
Chairman: C. F. C. SNEESBY, A.F.R.Ae.S.
Hon. Secretary: J. LUDFORD, A.R.Ae.S., Marshalls Flying School, Newmarket Road, Cambridge.

CHESTER
President: C. B. V. NIELSON.
Chairman: G. J. SALISBURY, A.R.Ae.S.
Hon. Secretary: H. STRAWSON, A.F.R.Ae.S., Thornton Research Centre, P.O. Box 1, Chester.

CHRISTCHURCH
President: E. W. J. GRAY, F.R.Ae.S.
Chairman: H. E. VINCENT, A.F.R.Ae.S.
Hon. Secretary: N. J. KENT, A.R.Ae.S., c/o Vickers-Armstrongs (Aircraft) Ltd., Hurn Airport, Christchurch.

COVENTRY
President: H. M. WOODHAMS, C.B.E., F.R.Ae.S.
Chairman: W. J. PETERS.
Hon. Secretary: C. T. SCULTHORPE, A.F.R.Ae.S., Sir W. G. Armstrong Whitworth Aircraft Ltd., Whitley, Coventry.

DERBY
President: J. D. PEARSON, F.R.Ae.S.
Chairman: A. A. RUBBRA, F.R.Ae.S.
Hon. Secretary: J. H. STEPHENS, A.F.R.Ae.S., c/o Rolls-Royce Ltd., Nightingale Road, Derby.

GLASGOW
President: Professor W. J. DUNCAN, C.B.E., F.R.Ae.S.
Chairman: Dr. A. W. BABISTER, A.F.R.Ae.S.
Hon. Secretary: W. N. ALCOCK, Shenstone, Dumbuck Crescent, Dumbarton.

GLOUCESTER AND CHELTENHAM
President: L. G. FAIRHURST, F.R.Ae.S.,
Chairman: J. F. CUSS, A.F.R.Ae.S.
Hon. Secretary: C. E. HUTT, A.R.Ae.S., c/o S. Smith and Sons (England) Ltd., Bishops Cleeve, nr. Cheltenham, Glos.

HALTON
President: Air Marshal H. D. SPRECKLEY, C.B., O.B.E., F.R.Ae.S.
Chairman: Air Commodore T. N. COSLETT, O.B.E.
Hon. Secretary: Sqn. Ldr. J. W. G. PARKER, E. & I. Squadron, R.A.F., Halton.

HATFIELD
President: Sir GEOFFREY DE HAVILLAND, C.B.E., A.F.C., Hon. F.R.Ae.S.
Chairman: C. G. LONG, A.F.R.Ae.S.
Hon. Secretary: J. A. KIRK, A.F.R.Ae.S., de Havilland Propellers Ltd., Hatfield, Herts.

HENLOW
President: R. HILLS, F.R.Ae.S.
Chairman: Wg. Cdr. I. D. H. GIBBINS, M.B.E., A.F.R.Ae.S.
Hon. Secretary: Flt. Lt. A. H. CRAVEN, A.F.R.Ae.S., Officer's Mess, R.A.F. Technical College, Henlow, Beds.

ISLE OF WIGHT
President: Sir ARTHUR GOUGE, Hon. F.R.Ae.S.
Chairman: W. BROWNING, F.R.Ae.S.
Hon. Secretary: R. L. WHEELER, A.F.R.Ae.S., Design Office, Saunders-Roe Ltd., Osborne, Isle of Wight.

LEICESTER
Chairman: K. B. AYERS, A.F.R.Ae.S.
Hon. Secretary: M. G. RUSSELL, A.R.Ae.S., c/o Design Office, Auster Aircraft Ltd., Rearsby, Leics.

LONDON AIRPORT
President: G. W. HALL, F.R.Ae.S.
Chairman: R. L. LICKLEY, F.R.Ae.S.
Hon. Secretary: N. BROWN, A.R.Ae.S., B.O.A.C. H.Q., London Airport, Middlesex.

LUTON
President: F. H. POLLICUTT, F.R.Ae.S.
Chairman: H. J. BROOKS, A.F.R.Ae.S.
Hon. Secretary: L. A. WILLOTT, A.F.R.Ae.S., Hunting Aircraft Ltd., Luton Airport.

MANCHESTER
President: Sir ROY H. DOBSON, C.B.E., J.P., Hon.F.R.Ae.S.
Chairman: C. E. FIELDING, O.B.E., F.R.Ae.S.
Hon. Secretary: J. A. E. WATERFALL, 56 Manor Avenue, Ashton-on-Mersey, Cheshire.

MERTHYR TYDFIL
President: C. S. GARDNER.
Chairman: J. INGRAM.
Hon. Secretary: Dr. G. O. FORESTER, Chief of Research, Teddington Aircraft Controls Ltd., Cefn Coed, nr. Merthyr Tydfil, South Wales.

PRESTON
President: Sir GEORGE H. NELSON.
Chairman: E. LOVELESS, A.F.R.Ae.S.
Hon. Secretary: J. F. FOSS, A.F.R.Ae.S., English Electric Avaition Ltd., Warton Aerodrome, nr. Preston.

READING
President: Sir FREDERICK HANDLEY PAGE, C.B.E., Hon.F.R.Ae.S.
Chairman: R. J. FENNER, A.F.R.Ae.S.
Hon. Secretary: N. KITCHING, A.R.Ae.S., Handley Page (Reading) Ltd., The Aerodrome, Woodley, Reading.

SOUTHAMPTON
Chairman: Professor E. J. RICHARDS, O.B.E., F.R.Ae.S.
Hon. Secretary: F. C. KIRKPATRICK, A.R.Ae.S., Folland Aircraft Ltd., Hamble, Southampton.

SOUTHEND
Chairman: T. R. C. BERRETT, A.R.Ae.S.
Hon. Secretary: K. A. COLE, A.R.Ae.S., c/o Aviation Traders (Eng.) Ltd., Southend Airport, Essex.

SWINDON
Chairman: S. R. HUGHES, A.F.R.Ae.S.
Hon. Secretary: D. RIGG, A.R.Ae.S., Vickers-Armstrongs (Aircraft) Ltd., Supermarine Works, South Marston, Swindon.

WEYBRIDGE
President: Sir GEORGE EDWARDS, C.B.E., F.R.Ae.S.
Chairman: H. H. GARDNER, F.R.Ae.S.
Hon. Secretary: E. G. BARBER, A.F.R.Ae.S., Vickers-Armstrongs (Aircraft) Ltd., Weybridge.

YEOVIL
President: E. C. WHEELDON.
Chairmen: D. L. HOLLIS-WILLIAMS, F.R.Ae.S. and Dr. E. W. STILL, F.R.Ae.S.
Hon. Secretary: L. A. LANSDOWN, A.F.R.Ae.S., Westland Aircraft Ltd., Yeovil.

NOTICES

The Burnham Committee

The Council is glad to announce that the Burnham Committee has decided to accept the Associate Fellowship of the Society for the purposes of the graduate addition, subject to certain provisos. The following is the letter received from the Honorary Secretary of the Committee:—

10 Queen Anne Street, London, W.1.
22nd January 1960

". . . . I am happy to be able to advise you that a decision has now been made accepting the Associate Fellowship of the Royal Aeronautical Society for the purposes of the graduate addition, provided that the teacher has obtained the qualification by examination and either

(*a*) Has passed one paper each from the following groups in Parts I and II of the Society's examination for Associate Fellowship
  (*i*) Advanced aerodynamics
  (*ii*) Theory of structures
  (*iii*) Aircraft design and development
  or examinations accepted by the Council as exempting the candidate from Parts I and II of the examination for Associate Fellowship.
  or
(*b*) Holds a Higher National Certificate or Higher National Diploma in Mechanical Engineering.

(*Signed*) W. P. Alexander *Hon. Secretary.*"

New Year's Honours List 1960

The President and Council congratulate the following members whose names were included in the New Year Honours List:—

K.B.E.	Admiral Sir Matthew Slattery (*Fellow*)
	Air Marshal H. D. Spreckley (*Fellow*)
C.B.	R. H. Weir (*Fellow*)
O.B.E.	Wing Cdr. R. Hill (*Associate Fellow*)
	Wing Cdr. L. Kendrick (*Associate Fellow*)
	A. Symon (*Associate Fellow*)
	P. H. Watson (*Associate Fellow*)
M.B.E.	E. J. Brunckhurst (*Associate Fellow*)
	H. Lloyd (*Associate Fellow*)
	F. M. Reynolds (*Associate Fellow*)
	Sqn. Ldr. B. Trodd (*Associate Fellow*)

Foreign Honorary Fellows of the Institute of the Aeronautical Sciences

The following members of the Society have been elected Foreign Honorary Fellows of the Institute of the Aeronautical Sciences:—

E. T. Jones (*Fellow*) Dr. van der Maas (*Fellow*)

The New By-Laws and Fellowship of the Society

The Council is pleased to announce that the new By-Laws of the Society have been allowed by the Privy Council and have been in operation since the 11th January. The By-Laws will be reprinted and distributed to all members in due course. Meanwhile, attention is drawn to the following extracts from By-Law 2 (*D*) applying to Fellowship of the Society;

"**Application** for Fellowship must be proposed by a Fellow and supported by three other Fellows. Every candidate for election into the class of Fellow shall be an Associate Fellow or possess the qualifications necessary for Associate Fellowship.

Furthermore, in the opinion of the Council:—

(*a*) He shall have made outstanding contributions in the profession of aeronautics *or*
(*b*) He shall have attained a position of high responsibility in the profession of aeronautics *or*
(*c*) He shall have had long experience of high quality in the profession of aeronautics".

National Council for Technological Awards

Sir Harold Roxbee Cox, a Past President of the Society, has been appointed Chairman of the National Council for Technological Awards in succession to Lord Hives. Sir Harold was formerly Vice-Chairman of the Council.

The British Rocket Programme

The Royal Astronomical Society and the Royal Meteorological Society will hold a Joint Discussion on The British Rocket Programme at the Royal Society of Arts, John Adam Street, London W.C.2, from 2.30 to 7 p.m. on Friday 4th March 1960.

Professor H. S. W. Massey will be the Opening Speaker and Chairman. Other speakers will be:— J. F. Hazell, E. B. Dorling, G. V. Groves, P. A. Sheppard, G. Best, J. Sayers, A. P. Willmore, R. L. F. Boyd, S. H. Hall and W. J C. Beynon.

All-Day Symposium on Vehicle and Instrumentation Problems in Upper Atmosphere Research

Mr. A. V. Cleaver (*Fellow*) will take the Chair for the Symposium on Vehicle and Instrumentation Problems in Upper Atmosphere Research, to be held at 9.45 a.m. on 11th March, at the Institution of Mechanical Engineers, 1 Birdcage Walk, S.W.1.

The programme will be as follows:—

Introduction, by Prof. H. S. W. Massey, University College; Skylark, by J. F. Hazell, R.A.E., Farnborough; Scientific Information from Skylark Programme, by Dr. R. L. F. Boyd, University College; Meteorological Measurements in the Upper Atmosphere, by Dr. G. D. Robinson, Meteorological Office, London; Range Instrumentation Problems in Upper Atmosphere Research, by H. J. Higgs, W.R.E. Representative, Ministry of Aviation; Future Possibilities, by E. C. Cornford, R.A.E., Farnborough.

Admission will be **by ticket only.** Tickets and programmes may be obtained from the Secretary, Royal Aeronautical Society, 4 Hamilton Place, London W.1., by members only until 4th March and thereafter to non-members.

The Thirteenth Louis Blériot Lecture

The Thirteenth Louis Blériot Lecture will be held at the Société des Anciens Elèves des Ecoles d'Arts et Métiers, 9 bis, Avenue d'Iena, Paris 16 on Wednesday 2nd March 1960.

The Lecture, entitled "Current Problems in Aero Engine Design," will be given by Dr. E. S. Moult, C.B.E., B.Sc., F.R.Ae.S., Technical Director of The de Havilland Engine Co. Ltd. Dr. Moult is President-Elect of the Royal Aeronautical Society.

Ties

The ties which have been especially designed for the Society, as mentioned by the Secretary in his News Letter in the December Journal, are now available.

The tie for members of the Society consists of gold falcons with wings outstretched (as on the Society's badge) on a navy blue background. They are silk, cost one guinea and are obtainable only from Rowans Ltd., Buchanan St., Glasgow.

A tie for Branch members, which has gold falcons on a maroon background, is now available from the Secretaries of the Branches, also at one guinea.

Dinner of the Past Presidents of the Society—An Apology

The name of Sir Harold Roxbee Cox was unfortunately omitted from the list of those present at the dinner of Past Presidents of the Society, which was published in the January Journal.

DIARY

LONDON

23rd February

LECTURE—Relationship Between Theory and Practice in Structural Problems. A. J. Troughton. Library, 4 Hamilton Place. 7 p.m.

24th February

MAN POWERED AIRCRAFT GROUP LECTURE—**Cancelled.**

2nd March

THIRTEENTH LOUIS BLÉRIOT LECTURE—**IN PARIS**—Current Problems in Aero Engine Design. Dr. E. S. Moult.

8th March

LECTURE—Electronic Microcircuits. Dr. J. W. Granville. Library, 4 Hamilton Place. 7 p.m.

11th March

SYMPOSIUM—All-Day Discussion on Vehicle and Instrumentation Problems in Upper Atmosphere Research. Institution of Mechanical Engineers, Birdcage Walk, S.W.1. 9.45 a.m. **Admission by ticket only.** *See Special Notice.*

15th March

LECTURE—Some Problems of Separated and Vortex Flow. Professor H. B. Squire. Library, 4 Hamilton Place. 7 p.m.

17th March

MAIN LECTURE—Supersonic Aircraft—Promise and Problems. M. B. Morgan. Institution of Mechanical Engineers, Birdcage Walk, S.W.1. 6 p.m. (Tea at 5.30 p.m.)

18th March

AGRICULTURAL AVIATION GROUP—Film Evening. Library, 4 Hamilton Place. 7 p.m.

24th March

MAIN LECTURE—Engines for Supersonic Airliners. Dr. R. R. Jamison. Institution of Mechanical Engineers, Birdcage Walk, S.W.1. 6 p.m. (Tea at 5.30 p.m.)

25th March

MAN POWERED AIRCRAFT GROUP LECTURE—Aerodynamics of Man Powered Flight. D. Perkins. Library, 4 Hamilton Place. 7 p.m.

ROTORCRAFT SECTION

4th March

British Research on the Aerodynamics of Powered Lift Systems. J. Williams. Library, 4 Hamilton Place. 6 p.m.

GRADUATES' AND STUDENTS' SECTION

24th February

Annual General Meeting and Film Show. Library, 4 Hamilton Place. 7.30 p.m.

9th March

The Hovercraft and its Development. W. J. Eggington. Library, 4 Hamilton Place. 7.30 p.m.

BRANCHES

22nd February

Cambridge—Film Show. No. 1 Lecture Hall, Cambridge University Engineering Laboratories. 8.15 p.m.

Halton—Third Trenchard Memorial Lecture. "A Dip into the Future . . ." Sir George Edwards. Burnett Gymnasium, R.A.F. Halton. 6.45 p.m.

24th February

Christchurch—Man Powered Aircraft. B. S. Shenstone. Kings Arms Hotel. 7.30 p.m.

Hatfield—The SR.N1 Hovercraft. R. Stanton-Jones. de Havilland Restaurant. 6.15 p.m.

Reading—The Car Ferry Operation and History of Silver City Airways. M. D. Day. Top Canteen, Western Manufacturing (Reading) Ltd. 6 p.m.

25th February

Belfast—Blind Landing. W. J. Charnley. Lecture Hall LG8, David Keir Building, Queen's University. 7 p.m.

Bristol—Junior Committee Lecture. The SR.N1 Hovercraft. R. Stanton-Jones. Filton House. 6 p.m.

Isle of Wight—The Economic Basis for the Design of a Freight Aircraft. A. H. Stratford. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6 p.m.

29th February

Yeovil—5th Henson and Springfellow Memorial Lecture—VTOL Aircraft. D. Keith-Lucas. Park School, Park Road. 7.30 p.m.

1st March

Luton—An Historical Lecture. C. F. Uwins. Lecture Hall, Luton College of Technology. 7 p.m.

2nd March

Brough—The Boeing 707. J. Sutter. Royal Station Hotel Writing Room. 7.30 p.m.

Preston—The Fairey Rotodyne. Dr. G. S. Hislop, R.A.F.A. Hall, Preston. 7.30 p.m.

Swindon—Flight Testing of Modern Prototype Aircraft. C. F. Bethwaite. The College, Victoria Road. 7.30 p.m.

Weybridge—Space Flight. Discussion by a panel of experts. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6.10 p.m.

4th March

Cambridge—The Work of an Air Correspondent. A. Macpherson. No. 1 Lecture Hall, Cambridge University Engineering Laboratories. 8.15 p.m.

London Airport—Film Show and Annual Dinner. Feltham Hotel, Feltham. 7 p.m.

7th March

Boscombe Down—Supersonic Civil Aircraft. R. G. Thorne. Lecture Hall, A. & A.E.E. 5.30 p.m.

Derby—Silencing of Jet Engines. F. B. Greatrex. Rolls-Royce Welfare Hall, Nightingale Road. 6.15 p.m.

Henlow—Design for Hypersonic Flight. H. Metcalfe. The Assembly Hall, R.A.F. Technical College, Henlow. 7.45 p.m.

8th March

Glasgow—Graduates' and Students' Section—Air Traffic Control. B. Job. Scottish Aviation Ltd., Prestwick. 7.30 p.m.

Gloucester—Aviation Medicine. Fl. Lt. J. Billingham. Wheatstone Hall, Brunswick Road. 7.30 p.m.

9th March

Chester—Brain's Trust. Lecture Theatre, Grosvenor Museum. 7.30 p.m.

Reading—The Applications of Thermo-setting Resins. E. A. Davies. Top Canteen, Western Manufacturing (Reading) Ltd. 6 p.m.

10th March

Bristol—Barnwell Memorial Lecture—The History of Bristol Aero-Engines. Sir Roy Fedden. Main Lecture Theatre, Faculty of Engineering, University of Bristol. 7 p.m.

Yeovil—The Philosophy of Patents. L. Hayward. Park School, Park Road. 7.30 p.m.

15th March

Glasgow—Lessons Learned from Aircraft Accidents. J. G. M. Pardoe. Royal College of Science and Technology. 7.15 p.m.

16th March

Christchurch—Lighter than Air Aircraft. The Rt. Hon. Lord Ventry. King's Arms Hotel. 7.30 p.m.

Coventry—The Hovercraft. G. H. Elsley. Herbert Art Gallery. 7.30 p.m.

Southampton—Seventh Mitchell Memorial Lecture. D. Keith-Lucas. Engineering Lecture Theatre, University of Southampton. 8 p.m.

17th March

Isle of Wight—Hovercraft. C. S. Cockerell. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6 p.m.

18th March

Birmingham and Wolverhampton—Branch President's Night. L. S. Greenland. H. M. Hobson Ltd., Wolverhampton. 7.30 p.m.

19th March

Merthyr Tydfil—The Evolution of the Digital Computer. R. W. Seymour-Lee.

21st March

Henlow—Visit to the Laboratories of the Aircraft Research Association.

22nd March
Cambridge—Film Show. No. 1 Lecture Hall, Cambridge University Engineering Laboratories. 8.15 p.m.
Luton—Annual General Meeting. Napier Senior Staff Canteen, Luton Airport. 6.15 p.m.
23rd March
Reading—Undercarriage Design Problems. J. Perdue and H. Pendlebury. Top Canteen, Western Manufacturing (Reading) Ltd. 6 p.m.
Weybridge—The V.C.10. E. E. Marshall. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6.10 p.m.
25th March
Bristol—Annual General Meeting and Film Show. Filton House. 6 p.m.
Hatfield—Annual Dinner.
Swindon—Annual Buffet Dance. Goddard Arms.

Elections

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Roy Atkin (*from Graduate*)
Denys Stanley Bliss (*from Graduate*)
Richard Harold Botterill (*from Associate*)
Kenneth John Bullock (*from Graduate*)
Roland Bryon Heywood
Maurice Evans King
Franklin William Kolk
Ronald Lyell McCallum (*from Associate*)
Walter Ormrod
Kenneth George Page (*from Graduate*)
Stuart Gregory Pountain (*from Graduate*)
Framji Minochehr Soonawalla (*from Graduate*)
Janis O. A. Stankevics (*from Graduate*)

Associates

Colin Morris Hanson
Christopher Richard Whitcomb

Graduates

George Frederick Ackroyd
George Harold Bleakley
Geoffrey William Bowen
John Robert Stewart Davidson (*from Student*)
James Ernest Hackett (*from Student*)
John Edmund Land
Peter George Oliver
John Allan Page
Brian Raybould
John Teesdale Shepherd
Margaret Janet Southcott
Russell Sowerby
David Robert Topham (*from Student*)
Denis Vivian Warren (*from Student*)
Wilfred Watson
Edward Alan White
Michael John Woods (*from Student*)

Students

John Anthony David Ackroyd
Richard Harry Barnard
Mary Barnes
Trevor Carris
Ivan Hill Dimmock
Terence Dixon
Alan Arthur Driver
Brian Charles Freeman
David Owen Hughes
Donald Frederick Charles Lamb
Peter Keith Manning
Kenneth Peyman Newby
Richard Graham Walker
Colin Arthur Widdison
Roy John Wiltsher
Colin Harold Winrow

Companions

John Trevor Thorpe

Supplement to Oxford English Dictionary

The following is the fifth list of aeronautical terms for the Supplement to the *Oxford English Dictionary* for which assistance in tracing early references is required. If members know of an earlier use than that given for any word in the following list they are asked to write to the Editor, Oxford English Dictionary Supplement, 40 Walton Crescent, Oxford, giving the reference(s), date, author, title, chapter and page. Earlier lists were published in the June, August, October and December 1959 Journals.

bail out, bale out (from aeroplane)	1930	D. Verrill, *Aircraft Book for Boys*
barrage balloon	1930	Augustus Post, *Skycraft*
beam approach	1944	*Electronic Engineering*
bleeding (expulsion of air)	1941	*Aeroplane Spotter*
blind, adv. (fly, land blind)	1928	A. Klemin, *If You Want to Fly*
blind approach beacon system (B.A.B.S.)	1936	C. B. Allen, *Wonder Book of the Air*
blind landing	1932	Ross Mahachek, *Airplane Pilot's Manual*
bomb bay	1934	*Flight*, 15th February
bomb door	1939	*Meccano Magazine*, March
bomb-dropping	1914	*Times*, 1st May
bomb-rack	1917	*Advisory Committee for Aeronautics: Reports and Memoranda*, No. 378
bombing run	1941	*ABC of the R.A.F.*
bomb run	1941	*Science Digest*, November
bombing sight	1928	*Daily Mail*, 16th August
bomb sight	1917	*Advisory Committee for Aeronautics: Technical Report* 1916/17
bombing up (loading)	1932	*Times*, 3rd November
bomb up (to load)	1941	*War Weekly*, 10th January

News of Members

Capt. W. Beets (*Associate*) formerly Deputy Engineer in Chief at the Ministerie van Defensie/Marine, The Hague, is now Deputy Director at Werkspoor N.V. Amsterdam.

J. A. Brennan (*Associate*) formerly with the Air Arm Division, Westinghouse Electric Corporation, is now Chief Mechanical Engineer, Pye Industrial Electronics Ltd.

D. J. Carey (*Associate Fellow*) formerly with V.T.O.L. Products Group, Canadair Ltd., Montreal, is now Senior Aerodynamicist, Bristol Aircraft Ltd. (Helicopter Division), Weston-Super-Mare.

L. R. A. Carter (*Associate*) formerly a Design Engineer, A. V. Roe Aircraft Ltd., Canada, is now a Senior Design Engineer, Vertol Aircraft Corporation, U.S.A.

Air Cdre. B. A. Chacksfield (*Associate Fellow*) formerly Director, Guided Weapons (Trials) Ministry of Supply and R.A.F. has been appointed Senior Air Staff Officer, Technical Training Command, with the acting rank of Air Vice-Marshal.

K. S. R. Child (*Associate Fellow*) formerly a Stress Engineer, North American Aviation, Columbus, is now a Senior Project Engineer, "Raytheon" Missile Systems, Bedford Laboratory, Massachusetts.

R. M. Cracknell (*Associate Fellow*) formerly Assistant Engineering Manager, de Havilland Propellers Ltd., is now Engineering Manager.

D. M. Davies (*Associate Fellow*) formerly at the University of Nottingham, is now H.M. Inspector of Schools (Technical Branch), Midland Division, centred in Birmingham.

K. G. Draper (*Associate Fellow*) formerly a Stressman with de Havilland Aircraft Co. Ltd., is now a Senior Stressman, Teleflex Products Ltd.

F. R. E. Flower (*Associate*) formerly with the Airborne and Helicopter Division, A. & A.E.E., Boscombe Down, is now Assistant R.T.O. at Westland Aircraft Ltd.

Sqn. Ldr. R. F. Gash (*Associate Fellow*) formerly in the Directorate of Weapons Engineering, Air Ministry, is now a Student at the R.A.F. Staff College, Bracknell.

R. K. Grinter (*Student*) formerly with the de Havilland Aircraft Co. Ltd., has been Commissioned in the Royal Air Force and is stationed at Colerne, Wilts.

Tibor Haas (*Associate Fellow*) formerly Head of the Fatigue Laboratory, Bristol Aircraft Ltd., is now Head of Design Service, British Welding Research Association, Cambridge.

J. B. Henshaw (*Student*) formerly Aircraft Engineering Apprentice with the de Havilland Aircraft Co. Ltd., is now a Technical Engineer, Bristol-Siddeley Engine Company.

V. HOLLINGWORTH (*Associate Fellow*) formerly Section Leader Draughtsman, Fairey Aviation Ltd., is now Assistant Type Engineer (Rotodyne) responsible for Liaison between British European Airways and Fairey Aviation Ltd., on all technical aspects of the Rotodyne.

Sqn. Ldr. D. K. KEMPSTON (*Associate Fellow*) formerly on the Technical Staff at Headquarters Far East Air Force, Changi, Singapore, and ex-Secretary of the Singapore Branch of the Royal Aeronautical Society, is now in the Directorate of Aircraft Engineering, Air Ministry, Whitehall.

W. KUZYK (*Associate Fellow*) formerly with John Orter Mfg. Co., Racine, Wisconsin, is now with Collins Radio, Cedar Rapids, Iowa, as Senior Assistant Engineer.

J. D. REDDING (*Associate Fellow*) formerly with the Westinghouse Electric Corporation, is now the Director, Military Applications, Remington Rand Univac, Division of Sperry Rand Corporation, Washington.

Sqn. Ldr. R. G. ROWE (*Associate Fellow*) formerly Technical Engineer at the Royal Air Force Technical College at Henlow, is now Technical Engineer, Royal Radar Establishment, Malvern.

DONALD A. SNOAD (*Associate*) formerly Senior Technical Author in Charge of Technical Publications Dept., Waymouth Gauges & Instruments Ltd. (a subsidiary of Smiths Aircraft Instruments Ltd.), is now a Senior Technical Author, Industrial Handbooks Ltd., London.

S. C. THORP (*Associate Fellow*) formerly Works Inspector, B.O.A.C., London Airport, is now Quality Control Engineer (Engineering and Maintenance).

Sqn. Ldr. G. B. TYLER (*Associate Fellow*) having completed a tour as Lecturer in Aerodynamics to Guided Weapons Courses at the R.A.F. Technical College, Henlow, has been posted to R.A.F., North Coates.

Lt. R. G. WADE (*Graduate*) formerly at R.N. Station, Abbotsinch, Paisley, has been appointed Sea Vixen D.D.P.O. in the department of D. (R.N.) A, in the Ministry of Aviation.

Summaries of Lectures

Astronautics and Guided Flight Section

MISSILE CONTROL PROBLEMS

by

DENIS BEST

Given on 18th February

The lecture illustrates some of the special design problems associated with "Twist and Steer" missile control. The relative merits of different forms of roll control are discussed and the influence of missile dynamic couplings is illustrated.

The essential non-linearity of the system has led to the evolution of special methods of representation and design which are briefly described.

In the case of homing missiles, design restrictions are imposed by the high rate of roll required. In spite of these, high overall performance can be attained.

RELATIONSHIP BETWEEN THEORY AND PRACTICE IN STRUCTURAL PROBLEMS: THE RELATIVE MERITS OF STRESSING AND TESTING IN AIRCRAFT STRUCTURAL DESIGN

by

A. J. TROUGHTON, A.F.R.Ae.S.

To be given on 23rd February

The lecture will discuss the best approach to ensure the structural airworthiness of an aircraft. In comparing the relative merits of stressing and testing the following standpoints are considered:—Final accuracy of result, time, developing the potential of the aircraft and the financial aspects. Typical examples are given where testing has proved the only method of reliable design evaluation. The comparative values of detail and full scale structural tests are demonstrated, together with their relative limitations. The question of covering static strength, fatigue life and fail safe characteristics as economically and realistically as possible is covered. The extent to which stressing must be carried out is considered in the light of its accuracy and influence on actual design.

Thirteenth Louis Blériot Lecture, 1960

CURRENT PROBLEMS IN AERO ENGINE DESIGN

by

E. S. MOULT, C.B.E., B.Sc., Ph.D., F.R.Ae.S., M.I.Mech.E.

To be given in Paris on 2nd March 1960

As a background to power plant requirements, the author first reviews the circumstances of the present situation and current trends in aircraft design. Among the major developments are the capability of very short or vertical take-off and the extension of civil transport to supersonic speeds.

Different types of engine are considered in an ascending scale of flight speeds. In its different forms the gas turbine is the best solution for speeds between Mach numbers of 0 and 3.

For vertical lift and short take-off, turbines offer good performance and the convenience of coupling propellers by shafting. Very light jet engines are being developed for vertical lift and in some cases their air flow is augmented by fans.

The author considers that most subsonic jet aircraft will soon adopt the ducted fan in one form or another. It gives more take-off thrust, better economy and less noise than the pure jet.

On the other hand, the pure jet will be used for supersonic flight and, above a Mach number of about 2·5 will be fitted with afterburners. At speeds above $M = 3{\cdot}0$ the ram-jet becomes an attractive engine but must be combined with the turbo-jet or other propulsive means for take-off and acceleration.

High temperature operation of the turbine is increasingly important and good progress is being made in the technique of cooling.

ELECTRONIC MICROCIRCUITS

by

Dr. J. W. GRANVILLE

To be given on 8th March 1960

Another milestone in the progress of electronics has been reached with the introduction of microminiaturisation techniques for electronic circuits. In this lecture, the principal microminiaturisation systems are described. These are (1) Micromodules; (2) Flat Plate Microcircuitry; and (3) Solid Circuits. The advantages and disadvantages of each system will be given. It is stressed that a reduction in size of electronic assemblies will not be generally acceptable unless the reliability is maintained or improved. The principal applications of microminiaturisation are discussed.

SOME PROBLEMS OF SEPARATED AND VORTEX FLOW

by

PROFESSOR H. B. SQUIRE

To be given on 15th March

Various types of vortex such as trailing vortices and the vortices formed by separation on slender wings with sharp leading edges are described. The "breakdown" of the latter type of vortex is discussed both theoretically and experimentally and related to similar phenomena in pipe flow. Some investigations of vortex flow occurring in hydraulics are mentioned.

A brief discussion is given of flow in the eddies which occur ahead of and behind steps, with the object of clarifying the principles which determine the main features of the field of flow. Heat transfer in this type of flow is also considered.

LECTURE THEATRE APPEAL

The following lists show further donations received up to the time of going to press.

Donations

Previous total (after minor adjustments)	**10567**	**2**	**3**
Associated Electrical Industries Ltd.	50	0	0
J. D. Ahlers, Esq.	5	10	0
N. A. H. Bailie, Esq.	50	0	0
A. P. H. Bamford, Esq.	1	0	0
Sqn. Ldr. P. J. Bardon	1	0	0
S. E. Beddall, Esq.	2	0	0
J. C. Bell, Esq.	1	1	0
J. P. Billingham, Esq.		10	0
Blackburn Aircraft Ltd.	2500	0	0
D. S. Bliss, Esq.	10	0	0
Boulton Paul Aircraft Ltd.	500	0	0
Bristol Branch	21	0	0
V. E. C. Brooks, Esq.	2	0	0
R. J. T. Bruce, Esq.	2	0	0
E. C. Brunning, Esq.	1	0	0
Inst. Lt. Cdr. J. W. Bugler	1	0	0
K. J. Bullock, Esq.	3	0	0
J. D. Burke, Esq.	10	0	0
B. Buss, Esq.	1	0	0
Sqn. Ldr. R. E. Cash	2	2	0
W. K. G. Causer, Esq.	1	0	0
G. D. Chapman, Esq.	4	0	0
Chester Branch	12	7	0
C. Christianson, Esq.	1	0	0
E. J. R. Clark, Esq.	4	0	0
Dr. J. S. Clarke	7	7	0
A. E. Clifford, Esq.	10	0	0
College of Aeronautics (Senior Common Room)	52	10	0
H. C. Collins, Esq.	2	0	0
W. H. Cooper, Esq.	1	1	0
C. Cope, Esq.	2	2	0
Coventry Branch	50	0	0
H. F. Cowley, Esq.	5	5	0
G. A. Cropper, Esq.	2	0	0
F. A. Dare, Esq.	2	2	0
B. J. Davey, Esq.	2	0	0
H. Dejardin, Esq.	4	0	0
Deposit Interest	72	0	0
Derby Branch	111	17	0
D. A. Drinkald, Esq.	2	0	0
P. J. Duncton, Esq.	3	3	0
Lt. R. M. Eden	2	0	0
H. T. Edgecombe, Esq.	2	2	0
J. E. Elliott, Esq.	1	10	0
English Electric (Preston Works) Sports and Social Association per Preston Branch	250	0	0
A. W. Fairlie, Esq.	1	10	0
Wg. Cdr. R. J. C. Farrell	2	2	0
A. W. Fia, Esq.	1	6	0
F. W. Free, Esq.	2	0	0
L. J. Geering, Esq.	1	0	0
W. W. Gibb, Esq.	2	2	0
C. Gibson, Esq.	1	0	0
R. G. R. Goldby, Esq.	5	0	0
Graduates and Students at Handley Page Ltd. (*see* separate list)	7	0	0
E. Gray, Esq.	2	2	0
Flt. Lt. J. R. Green	1	1	0
A. E. Harris, Esq.	1	0	0
A. G. Hayes, Esq.	2	2	0
K. H. Haywood, Esq.	2	0	0
M. J. Henwood, Esq.	5	0	0
J. M. Holmes-Walker, Esq.	1	0	0
E. Isherwood, Esq.	1	0	0
H. Jeffree, Esq.	6	0	0
K. J. Ker, Esq.	1	1	0
D. Key, Esq.	1	0	0
V. H. Knight, Esq.	1	0	0
F. W. Kolk, Esq.	1	1	0
J. H. Larrard, Esq.	5	5	0
Z. S. Lenkiewioz, Esq.	3	3	0
D. O. Lewis, Esq.	3	0	0
R. Lewis, Esq.	3	0	0
London Airport Branch	16	0	0
C. G. Milner, Esq.	1	0	0
G. E. Monger, Esq.	1	1	0
W. G. Murray, Esq.	2	2	0
Dr. S. Neumark	3	3	0
Sqn. Ldr. J. S. Newman	3	3	0
Prof. A. S. Niles	3	0	0
S. Oldfield, Esq.	3	0	0
J. D. Oliver, Esq.	1	1	0
W. M. Owens	1	1	0
J. A. Ploszajski, Esq.	3	3	0
Gp. Capt. J. A. R. M. Reid	2	2	0
P. W. Richards, Esq.	1	0	0
Flt. Lt. W. R. Roberts	1	7	0
Gp. Capt. B. Robinson	2	2	0
W. McLeod Ross, Esq.	1	0	0
B. E. Rowed, Esq.		10	0
T. Rowntree, Esq.	2	2	0
Flt. Lt. W. B. K. Searle	1	0	0
G. J. Shorey, Esq.		10	6
Dr. D. A. Spence	1	0	0
A. J. Troughton, Esq.	2	2	0
D. J. Tyler, Esq.	1	0	0
United Steel Companies Ltd. (Steel Peech and Tozer Ltd.)	100	0	0
Dr. P. A. Vasavada	1	1	0
P. J. Walker, Esq.	1	0	0
Weybridge Branch	33	1	0
G. H. W. Wharton, Esq.	1	1	0
Sqn. Ldr. J. Whelan	2	2	0
P. Whitford, Esq.	1	1	0
R. A. Wigginton, Esq.	1	1	0
M. V. Wignall, Esq.	2	2	0
Sqn. Ldr. E. F. C. Worthy	3	0	0
Yeovil Branch	22	0	0
	4055	2	6
	£14622	**4**	**9**

7-Year Covenants

Previous total (after minor adjustments)	**5391**	**12**	**10**
Flt. Lt. C. J. Adey	1	1	0
W. R. Bendall, Esq.	1	0	0
Sqn. Ldr. B. Brownlow	1	1	0
Wg. Cdr. T. R. Cave Browne-Cave	4	0	0
R. W. G. Gandy, Esq.	2	0	0
S. J. T. Harvey, Esq.	2	2	0
D. P. Huddie, Esq.	1	0	0
W. H. McKinlay, Esq.	1	0	0
D. Parker, Esq.	1	0	0
J. R. Stevens, Esq.	1	0	0
H. Strawson, Esq.	1	1	0
Ultra Electronics Ltd.	50	0	0
	66	5	0
	***£5457**	**17**	**10**

**With Income Tax at the present standard rate of 7s. 9d. in the £ this figure should produce £62377 (approx.) over the 7-year period.*

10-Year Covenants

Previous total	***£1612**	**10**	**0**

**With Income Tax at the present standard rate of 7s. 9d. in the £ this figure should produce £26325 (approx.) over the 10-year period.*

Annual Payments (unspecified period)

Previous total	**£83**	**8**	**0**

GRAND TOTAL £103,407

(approximately)

Further promises amounting to **£3408** *had been received up to the time of going to press, and donations in kind promised by firms are valued at* **£3500** (*approx.*)

The following have also subscribed but do not wish the amounts of their contributions to be published:—

M. C. Bampton, Esq.
S. Buchanan, Esq.
F. B. Goodall, Esq.
Wg. Cdr. W. R. Hardeman
A. A. Jacobs, Esq.
J. A. Kirk, Esq.
J. A. Lambert, Esq.
A. B. Lowe, Esq.
J. R. Robinson, Esq.
J. D. Storer, Esq.
W. F. W. Urich, Esq.
Flt. Lt. W. Warhaftig
A. C. Willmer, Esq.
F. S. Wood, Esq.

Graduates and Students at Handley Page Ltd.

The following donated to the total listed in the main list of donations:—

D. J. Isaaks, Esq.
R. T. Heath, Esq.
N. Thompson, Esq.
B. F. Tame, Esq.
D. Rodgers, Esq.
R. Free, Esq.
W. Blakeley, Esq.
B. J. Taylor, Esq.
B. H. Brasier, Esq.
J. H. Davies, Esq.
R. S. Pointer, Esq.
J. W. Jordan, Esq.
B. J. Willcox, Esq.
R. Charlesworth, Esq.
R. A. Newnham, Esq.
R. A. Miller, Esq.
M. S. Reeves, Esq.
R. K. Foster, Esq.
R. Godson, Esq.
N. J. B. Ritchie, Esq.
R. H. Burrin, Esq.
D. B. Sherriff, Esq.
D. W. Black, Esq.
A. G. Baker, Esq.
J. R. Starkey, Esq.
P. D. Chappell, Esq.
E. J. Harding, Esq.
B. Carter, Esq.
M. Pavitt, Esq.
J. A. Page, Esq.

Man Powered Flight

The Regulations and Conditions governing the award of the £5,000 prize offered by Mr. Henry Kremer, which is to be known as the Kremer Competition, have now been laid down by the Royal Aeronautical Society and are as follows:—

This Competition shall be conducted by the Royal Aero Club of the United Kingdom under the Regulations and Conditions laid down by a Committee called the KREMER COMPETITION COMMITTEE, which shall be composed of members of the Royal Aeronautical Society and of the Royal Aero Club. The Kremer Competition Committee is hereinafter referred to as "The Committee".

NOTE:—The Aircraft will be considered as Gliders and no Permit to Fly or Certificate of Airworthiness will be required. All intending entrants are strongly advised, during trials, to hold adequate insurance cover for all Third Party Risks, and to take every precaution against damages to property.

REGULATIONS

1. GENERAL
The prize will be awarded to the entrant who first fulfils the conditions.

2. PRIZE
The prize is £5,000 sterling.

3. ELIGIBILITY
The entrant, designer and pilot must be citizens of the United Kingdom or the British Commonwealth. The aircraft must be designed, built and flown within the British Commonwealth.

4. CONDITIONS OF ENTRY

4.1 *Aircraft*

4.1.1 The machine shall be a heavier-than-air-machine.

4.1.2 The use of lighter-than-air gases shall be prohibited.

4.1.3 The machine shall be powered and controlled by the crew of the machine, over the entire flight.

4.1.4 No devices for storing energy either for take-off or for use in flight shall be permitted.

4.1.5 No part of the machine shall be jettisoned during any part of the flight including take-off.

4.2 *Crew*

4.2.1 The crew shall be those persons in the machine during take-off and flight, and there shall be no limit set to their number.

4.2.2 No member of the crew shall be permitted to leave the aircraft at any time during take-off or flight.

4.2.3 One handler or ground crew shall be permitted to assist in stabilising the machine at the wing tip during take-off.

4.3 *Ground Conditions*

4.3.1 All attempts, which shall include the take-off run, shall be made over approximately level ground and on a course to be approved by The Royal Aero Club.

4.3.2 All attempts shall be made in still air, which shall be defined as a wind not exceeding a mean speed of approximately 10 knots, over the period of flight.

4.4 *Course*

4.4.1 The course shall be a figure of eight, embracing two turning points, which shall be not less than half a mile apart.

4.4.2 The machine shall be flown clear of and outside each turning point.

4.4.3 The starting line, which shall also be the finishing line, shall be between the turning points and shall be approximately at right angles to the line joining the turning points.

4.4.4 The height, both at the start and the finish, shall be not less than ten feet above the ground, otherwise there shall be no restriction in height.

4.4.5 The machine shall be in continuous flight over the entire course.

4.5 *Observation*
Every attempt shall be observed by the Royal Aero Club or by any body or persons authorised by the Royal Aero Club to act as observers.

5. APPLICATION FOR ENTRY

5.1 Entry forms shall be obtained from the Royal Aero Club, Aviation Centre, 19 Park Lane, W.1.

5.2 The entry fee shall be £1 which shall be refunded upon the attempt taking place.

5.3 Each application form for entry shall contain an application for Official Observation of the competitor's attempt.

5.4 The fee for Official Observations shall be £15 15s. 0d. which shall be forwarded with the application form.

5.5 The entrant shall undertake to abide by the conditions for Official Observation as set out on the application form and shall undertake to defray all expenses incurred in connection with the Official Observation of the attempt.

5.6 Entry forms and applications for Official Observation of an attempt must be received by the Royal Aero Club at least thirty days prior to the proposed date of the attempt. Applications will be considered in order of receipt at the Royal Aero Club Aviation Centre.

6. GENERAL CONDITIONS

6.1 *Insurance*
The entrant must undertake to insure, on behalf of himself, his pilot(s), crew, representatives or employees, against third party risks in connection with the attempt to a minimum amount of £20,000. Evidence that such insurance has been effected must be produced to the Official Observers prior to the attempt.

6.2 *Eligibility*
In any question regarding the acceptance of entries, eligibility of entrant, pilot, crew or aircraft under these Regulations, the decision of the Committee shall be final.

6.3 *Supplementary Regulations*
The Committee reserves the right to add to, amend or omit any of these regulations and to issue Supplementary Regulations.

6.4 *Interpretation of Regulations*
The Interpretation of these Regulations or any of the Regulations hereafter issued shall rest entirely with the Committee. The entrant shall be solely responsible to the Official Observers for due observance of these Regulations and shall be the person with whom the Official Observers will deal in respect thereof, or any other question arising out of this Competition.

6.5 *Revision of Regulations*
These Regulations shall remain in force for a period of two years from the date of publication. After this time, the Royal Aeronautical Society reserves the right to review and amend these Regulations if the prize has not been won.

The Journal of the Royal Aeronautical Society

IN WHICH ARE INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 64 FEBRUARY 1960 NUMBER 590

The Third Lanchester Memorial Lecture

THE Third Lanchester Memorial Lecture, "Some Developments in Boundary Layer Research in the past Thirty Years," by Professor Dr. H. Schlichting, was given on 26th November 1959 at Church House, Westminster, London. Mr. Peter G. Masefield, M.A., F.R.Ae.S., Hon.F.I.A.S., M.Inst.T., President of the Society, presided.

Mr. Peter G. Masefield: This is the third Lanchester Memorial Lecture delivered before The Royal Aeronautical Society. We are delighted to welcome our lecturer of this evening—Professor Dr. Hermann Schlichting, a distinguished German scientist. In the short history of the Lanchester Lecture we have already had contributions from two of the most brilliant scientists in the aeronautical sphere. The first was given by Dr. Theodore von Kármán and the second by Professor Collar of Bristol University, a Vice-President of the Royal Aeronautical Society. This evening they are joined by Professor Dr. Schlichting.

Before I ask him to deliver his lecture, and before I say a little more about him, I want to recall for a moment or two the subject of our Memorial Lecture—Dr. Frederick William Lanchester, to whose memory we do honour this evening.

We are delighted to have with us on this occasion both Mrs. Lanchester, the widow of our commemorated great man, and also his brother, Mr. George Lanchester, who for many years worked so closely with him.

Dr. Lanchester is recognised today as one of our most distinguished early pioneers of the Aeronautical sciences. His name will rank in after years with those of Cayley and Froude, prophets of their times. Lanchester was a man of great scientific versatility. In particular, he made major contributions to early knowledge of aerodynamics, and no less to the motor car industry. The Lanchester motor cars, which we can still see on the roads today, were always masterpieces of ingenuity. It is sad that, in recent years—but only very recently—they have ceased to appear each year at the Motor Show.

I have here the model of an aeroplane made by Lanchester in 1894. This was nine years before the Wright Brothers achieved powered controlled flight. This model aeroplane with two propellers behind the tail is six feet long and weighs only twenty ounces. The photograph shows Lanchester as many of us knew him in his later years; in fact, at the time when he delivered his last lecture before this Society—that was on the 12th November 1936, just twenty-three years ago. His subject was "The Part Played by Skin-Friction in Aeronautics."

It is worth recalling also that in a discussion after that lecture, twenty-three years ago, the great Charles Walker—C. C. Walker of de Havilland's—paid tribute to Lanchester. This great British aeronautical engineer said that "British aviation has a very great debt to Lanchester because right at the beginning he closed up all the gaps in science and thus made it possible to avoid researches and experiments into unfruitful fields." He also referred to Lanchester as a "Prophet," which drew from the doctor a characteristic reply, "Anyway, as far as concerns aeronautics, I may be a prophet, but certainly not a profiteer."

Mr. Wimperis, the President of the Society at that date, said that Lanchester was held in deep respect, and indeed affection, by the entire Royal Aeronautical Society. That is certainly true today as it was then.

Now I turn from the man we commemorate to the man whom we are gathered to hear this evening. This Third Lanchester Memorial Lecture, to be delivered by Dr. Hermann Schlichting, is on "Some Developments in Boundary Layer Research in the past Thirty Years." Now Schlichting is rather a difficult name, if you will excuse me, Doctor, for an Englishman to get his tongue around. So, if you will feel that it is no disrespect to you, I am going to call you "Dr. S."

"Dr. S." has been intimately concerned with work on boundary layer theory ever since 1930, when he became first of all an assistant to the great Professor Prandtl, whom we all revere in this country. Dr. Prandtl delivered the 15th Wilbur Wright Memorial Lecture before the Society in 1927, on "The Generation of Vortices in Fluids of small Viscosity," in which he referred to the Lanchester-Prandtl theory of aerofoils—the "Aerofoil Theory." He said at that time that "when Lanchester's 'Aerodynamics' came out in 1907, we in Germany were perhaps better able to understand Lanchester's book than were you in England," and went on: "English scientific men indeed have been reproached for the fact that they make no attempt to master the theories expounded by their own countrymen, whereas we in Germany study them closely and derive considerable benefit therefrom." I think it is fitting that after such a tribute Dr. Lanchester himself seconded Sir Sefton Branker's vote of thanks to Professor Prandtl's lecture.

F. W. Lanchester, *Honorary Fellow.*

Now we have a disciple of Prandtl here with us tonight. "Dr. S." is, in fact, the tenth distinguished German to lecture before this Society and the first for twenty years. His predecessors have included such famous names as Wronsky, Dornier, Lippisch, von Gronau and Focke. "Dr. S." was born in 1907 and he is today Professor of Fluid Mechanics at the Technical University of Braunschweig. He is also Director of the Aerodynamische Versuchsanstalt at Göttingen, and Head of the Institute of Aerodynamics of the Deutsche Forschungsanstalt fur Luftfahrt at Braunschweig.

I ask Professor Dr. Schlichting to deliver his Third Lanchester Memorial Lecture on "Some Developments in Boundary Layer Research in the Past Thirty Years."

The Third Lanchester Memorial Lecture

Some Developments in Boundary Layer Research in the Past Thirty Years

by

PROFESSOR DR. H. SCHLICHTING

(Professor at the Technical University of Braunschweig, Director of the Aerodynamische Versuchsanstalt, Göttingen, and Head of the Institute of Aerodynamics of the Deutsche Forschungsanstalt für Luftfahrt, Braunschweig.)

SUMMARY: Boundary layer theory is the cornerstone of our knowledge of the flow of air and other fluids of small viscosity under circumstances of interest in many engineering applications, especially also in aeronautics. Many complex problems in aerodynamics, as for instance the problem of skin friction, which was theoretically attacked very early by F. W. Lanchester, have been clarified by studying the flow within the boundary layer and its effects on the general flow around the body.

Research work on boundary layers, as started by Prandtl in 1904, was for the first twenty years—up to Prandtl's Wilbur Wright Memorial Lecture to the Royal Aeronautical Society in 1927—almost entirely restricted to Prandtl's Institute at Göttingen. But since about 1930 boundary layer theory has been generally accepted, and in the past thirty years there has been an almost exponential rise of the number of contributors to its further development.

The author tries to trace certain lines, along which this important branch of modern fluid dynamics has developed in the past thirty years. In this connection the following topics are treated to some extent:

I. Transition from laminar to turbulent flow.
II. Boundary layer control for high lift and low drag of aerofoils.
III. Aerodynamic heating at high speed (high Mach numbers).
IV. Boundary layer effects on swept wings and on rotating bodies.

I. The theoretical investigations of the problem of transition start from Reynolds' and Lord Rayleigh's hypothesis of the instability of laminar flow. After many unsuccessful attempts Tollmien, 1930, finally succeeded in calculating the critical Reynolds number for the boundary layer on a flat plate. More than ten years later Tollmien's stability theory was completely confirmed by very careful experiments of Dryden and his co-workers.

II. After many wind tunnel experiments the investigations of boundary layer control for high lift of aerofoils led to the construction of two aeroplanes with boundary layer suction at the Aerodynamische Versuchsanstalt Göttingen, in 1938, which were quite successful. Later on, also, a considerable reduction of the skin friction of aerofoils was obtained with the advent of the laminar flow aerofoil.

III. In flow at high Mach numbers the velocity boundary layer is accompanied by a thermal boundary layer which is caused by frictional heating. The large increase in the temperature of a solid surface in a high speed stream which can be calculated from boundary layer theory only, poses a serious problem to aeronautical engineers ("thermal barrier").

IV. The aerodynamic characteristics of swept wings and Delta wings are largely governed by the behaviour of their boundary layer. Some of the draw-backs of such wing plan forms can be remedied by boundary layer control, as for instance by a "boundary layer fence." For turbo-machines the influence of the centrifugal forces on the boundary layer plays an important role for their aerodynamic coefficients.

1. Introduction

I am well aware of the honour conferred on me by the invitation to deliver the third Lanchester Memorial Lecture. The first Lanchester Memorial Lecture was delivered by Professor von Kármán[1] in 1957, and the second was given by Professor A. R. Collar[2] in 1958. If we look a little further back into history and consider also the Wilbur Wright Memorial Lectures which have taken place annually in England since 1913, we find that the last such lecture which was delivered by a German to this Society occurred in 1927. It was then that Professor Prandtl[3] read before this Society the Fifteenth Wilbur Wright Memorial Lecture. It was in the same year that I joined Professor Prandtl's Institute at Göttingen as a young student. I completed my Doctor's thesis in that Institute in 1930 and remained in it until 1935. More than twenty years later, in 1957, I have returned to Göttingen, succeeding Professor Betz.

In his Wilbur Wright Memorial Lecture which he gave in 1927, Professor Prandtl included a survey of a branch of fluid mechanics which is closely linked with his own name, and with that of Lanchester, in that he spoke about the generation of vortices in fluids of small viscosity. In modern treatises this subject is referred to as Prandtl's Boundary Layer Theory. Prandtl[4] initiated this theory with his lecture "On fluid motion at very small viscosity" (Ueber Flüssigkeitsbewegung bei sehr kleiner Reibung), held before the Mathematical Congress at Heidelberg in 1904. With this lecture he paved a new way for the theoretical analysis of fluid motions with friction. This new way proved to be extremely fruitful and gave a powerful impetus to the development of applied aerodynamics.

Boundary layer theory finds its application to many important engineering problems. In this connection it is worth mentioning the problem of calculating the drag

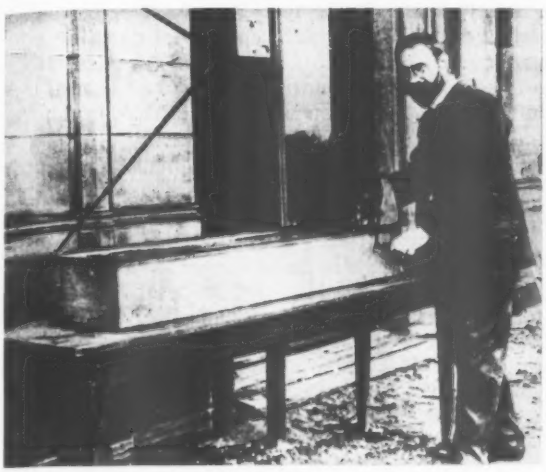


FIGURE 1. Professor Prandtl with his water channel investigating boundary layers, 1904.

of bodies placed in fluid streams, the drag of ships, of wings and of aircraft bodies. Boundary layer theory supplied an answer as to the form that it is necessary to give to a body in a stream, or to a channel containing a stream, in order to avoid deleterious separation. This is important in the study of problems connected with the flow of fluids through cascades of blades in turbomachinery. Further, the phenomena which occur when an aerofoil attains its maximum lift, as well as those associated with flows past swept and delta wings, which all involve separation, would be incomprehensible, if boundary layer theory did not exist. Another important field of application is linked with problems of the transfer of heat between solid bodies and fluids in motion, including those which arise when a solid body is heated by friction at very high speed.

All these important problems of modern fluid mechanics could be successfully tackled and solved to a large extent by the application of the basic ideas which Prandtl laid down in his Heidelberg Lecture in 1904. His theoretical considerations were even then supported by very simple experiments which he carried out in a primitive water channel shown in Fig. 1.

It seems to me that this work of Prandtl has close relation to the early work of F. W. Lanchester. In his book on Aerodynamics, of 1907, Lanchester is well aware of the concept that the flow around a body is governed by the "condition of no slip" at the wall and that there is a thin layer of retarded flow in the vicinity of the wall, which causes the skin friction. Lanchester also predicted correctly the basic law of laminar skin friction, namely that the skin friction is proportional to the 1·5 power of the velocity, that is to $V^{3/2}$. Lanchester[5] also fully recognised the importance of the boundary layer for the separation of the flow and the wake behind blunt bodies.

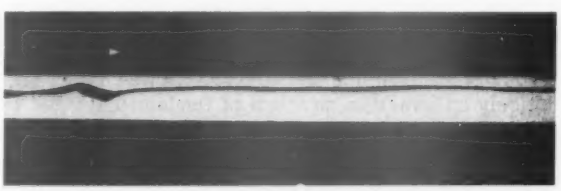
When Prandtl lectured on his boundary layer theory before this Society in 1927, it was fair to say that its development was then almost exclusively due to the efforts of scientific research in Germany. At that time the contemporary status of boundary layer research could still be adequately described by Tollmien in two short contributions to the "Handbuch der Experimentalphysik" in 1931. Prandtl's comprehensive survey[6] in Durand's "Aerodynamic Theory" did not follow until several years later (1935).

It was not long before 1930 that the study of boundary layer theory started to evoke great interest in other countries. According to a recent article written by H. L. Dryden[7], the number of contributions to boundary layer theory which is being currently published per annum has exceeded the one hundred mark. The branch of fluid mechanics under consideration, like many others, has thus grown to such an extent that it can hardly be grasped by a single man. Consequently, and rightly so, it has now become the custom to parcel it out among many authors when handbooks on it are being written. Nevertheless, some years ago I made an effort to write a comprehensive book on the subject[8] which has met with some recognition.

In this lecture I shall now endeavour to present to you certain lines along which this important branch of modern fluid dynamics is being developed and to report on some of the results. I shall confine myself to the period after about 1930, *i.e.* to that which followed the delivery of Prandtl's Wilbur Wright Memorial Lecture. This will bring into relief the fact that Prandtl's ideas proved to be so extremely fruitful.

Evidently, I shall be forced to restrict myself to several subdivisions of boundary layer theory. Thus I propose to choose these in a manner which will emphasise the influence of Prandtl's fundamental concepts on modern aircraft design. In particular, I propose to deal with the following headings: —

(*a*) Transition from laminar to turbulent flow.
(*b*) Boundary layer control for high lift and low drag.
(*c*) Boundary layers at very high speed (aerodynamic heating).



(*a*) Laminar flow, Re = 1150

(*b*) Turbulent flow, Re = 2520
Re = wd/ν = Reynolds number.

FIGURE 2. Laminar and turbulent flow of water in a pipe. Reynolds' dye experiment.

FIGURE 3. Turbulence originating from a natural disturbance in the boundary layer on a flat plate. Flow of water, from Prandtl[73].

(*d*) Three-dimensional boundary layers on swept wings and rotating bodies.

Beyond these topics boundary layer theory has many other fruitful applications, which cannot be dealt with here.

2. Transition

Transition from laminar to turbulent flow is not only an important problem of fundamental research in fluid mechanics but possesses many practical ramifications. For example, the drag of a body placed in a stream, as well as the rate at which heat is transferred from a solid wall to a fluid moving past it, depend very strongly on whether the flow in the boundary layer is laminar or turbulent. O. Reynolds[9] was first to perform fundamental experiments on transition, as early as in the eighties of the last century. He then discovered the principle of similarity, known by his name, which asserts that transition is determined by the Reynolds number

$$\mathrm{Re}=\frac{wl}{\nu}.$$

Here w denotes a characteristic velocity, l a characteristic length of the solid body and ν the kinematic viscosity of the fluid. Fig. 2 shows the well-known picture of laminar and turbulent flow of water in a pipe, as first given by Reynolds. When the Reynolds number is low, the flow is laminar, becoming turbulent at high values of it. Transition is said to be determined by the critical value of the Reynolds number.

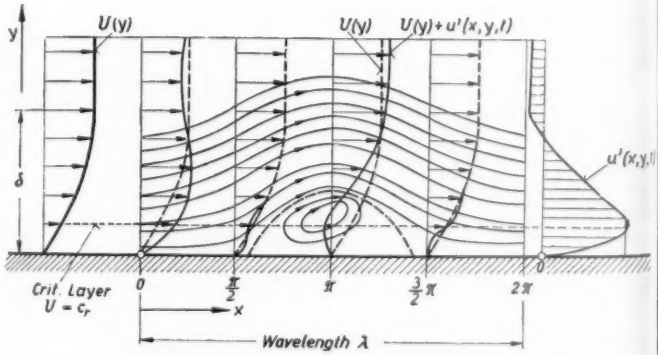
Lord Rayleigh[10] also occupied himself very early with the physical causes of transition. Both Lord Rayleigh and Reynolds formulated the hypothesis that transition can be traced to an instability of the basic laminar flow pattern in the sense that the latter becomes unstable when a certain critical value of the Reynolds number is reached; this causes the flow eventually to become turbulent. This hypothesis, due to Reynolds, formed the basis of the majority of the theories which addressed themselves to the problem of transition. Nevertheless, many years were to elapse before the validity of this hypothesis became apparent.

When laminar flows are analysed for stability, it is assumed that there is superimposed on them a disturbing flow, for example, a harmonic progressing wave. The decision as to whether the flow is stable or unstable is reached after an examination of the change in the form of the wave. Stable motions correspond to its decay, whereas instability is connected with its amplification.

During the first decades of this century, say until the year 1930, the theory under consideration remained devoid of success. Until then, all flow patterns which were examined with its aid appeared to be stable at *all* Reynolds numbers. Thus it was impossible to demonstrate the existence of the type of instability postulated by Reynolds.

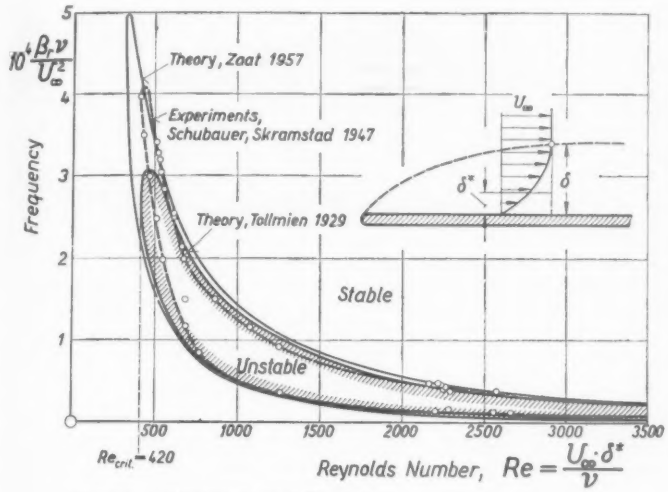
Nevertheless, Prandtl was not satisfied with this state of affairs and, as was his custom, he took refuge in the laboratory where he performed careful observations in order to acquire further inspiration for his theoretical investigations.

The views on transition which prevailed at the beginning of the twenties were aptly summarised by L. Prandtl[11] in an article in the "Zeitschrift für



$U(y)$ = velocity distribution of main flow;
$u'(x, y, t)$ = velocity distribution of a superimposed neutral disturbance.

FIGURE 4. Stream lines and velocity distribution of the disturbed boundary layer on a flat plate (stability theory), from H. Schlichting[15].



Theory—Tollmien[14] and Zaat[75].
Experiments—Schubauer and Skramstad[16].

FIGURE 5. Curves of neutral stability for the boundary layer on a flat plate (stability theory).

Angewandte Mathematik und Mechanik," 1921, when he said: —

"In order, then, to find out how turbulence really occurs in nature I had a long open tank made at Göttingen. The tank was 15 cm. wide, 25 cm. deep and 6·5 m. long. In it I observed the motion, having made it visible by Ahlborn's method (*i.e.* by sprinkling lykopodium). I fully expected that the mechanism of transition would become immediately apparent, but in that I was at first completely disappointed; I could then only establish that it *did* occur.

"Suddenly, without any visible prior indications small eddies sprang into existence in the vicinity of the wall and then proceeded to multiply fast in number. In addition, I could sometimes see wavy forms of slowly increasing amplitudes, but these did not invariably lead to actual turbulence. The existence of these waves of increasing amplitude does, however, entirely negate the dogma that laminar motions are completely stable with respect to small oscillations and therefore I was at first inclined to believe that I did not correctly observe this, not very frequent, phenomenon."

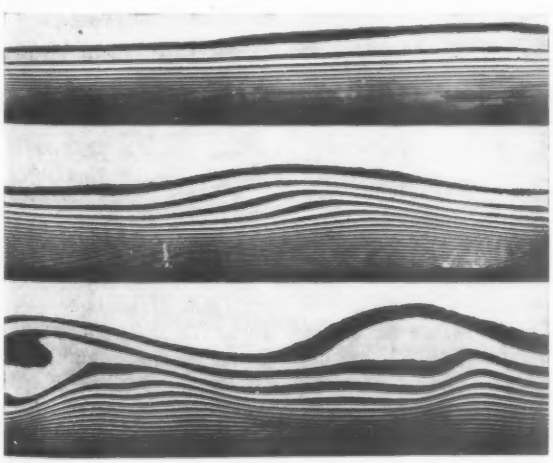


FIGURE 6. Disturbed boundary layer on a heated flat plate with natural convection. Flow pictures by interferometer method, from E. R. G. Eckert[17].

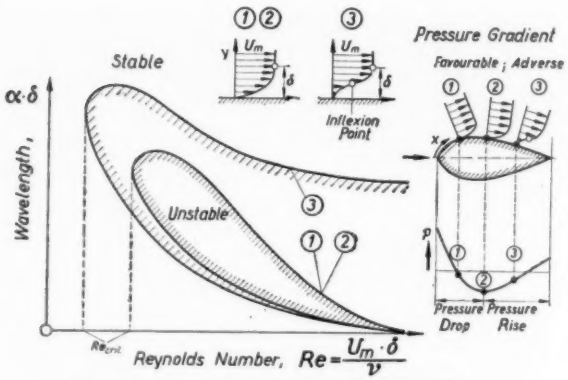
The picture in Fig. 3, which was taken in Göttingen several years later, gives a good idea of the observations which Prandtl described in this article. Prandtl then continued laconically: —

"We then addressed ourselves to the theoretical study of transition."

These theoretical investigations into the origin of turbulence which were carried on during the succeeding years in Göttingen by Prandtl, O. Tietjens[12], W. Heisenberg[13] and W. Tollmien[14] were crowned with success, only after ten years of sustained effort. It then became apparent that the simplifications introduced into the earlier investigations had been too drastic. The first calculation which led to a critical Reynolds number which agreed tolerably well with experiment was obtained when the stability calculation included the effect of the curvature of the laminar velocity profile, as well as the effect of the viscosity of the fluid in a correct manner. This decisive breakthrough in the stability theory was achieved by W. Tollmien[14]. A clear and simple idea of the picture pointed by this theory can be obtained from an examination of Fig. 4. This represents the pattern of streamlines as well as the velocity profile of the flow along a flat plate when a perturbation is superimposed on the mean motion[15]. The diagram involves a so-called neutral disturbance, that is one which lies just on the border between stability and instability. The similarity between this theoretical pattern of streamlines and the photograph of an actual flow, given in Fig. 3, as it was observed by Prandtl, is undeniable.

The most fundamental result provided by this stability theory appears in the form of a curve of neutral stability. Fig. 5 shows such a curve of neutral stability for the boundary layer on a flat plate at zero incidence. The curve supplies the locus of neutral frequencies in terms of the Reynolds number. The theory leads to the conclusion that at low Reynolds numbers all frequencies (wavelengths) of the perturbation are damped, whereas at high Reynolds numbers there exist two discrete frequencies which are neither damped nor amplified, but are neutral. These two neutral frequencies trace the curve of neutral stability which encompasses the domain of amplified oscillations.

The experimental verification of the preceding theoretical results needed a further decade to become realised. After many vain attempts, H. L. Dryden and his co-workers G. B. Schubauer and H. K. Skramstad[16]



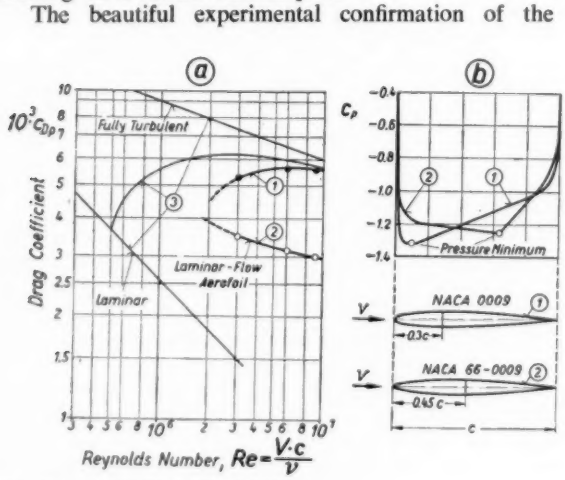
(1) Pressure gradient $dp/dx < 0$, favourable.
(2) $dp/dx = 0$.
(3) $dp/dx > 0$, adverse.

FIGURE 7. Curves of neutral stability for the laminar boundary layer with favourable and adverse pressure gradient, theory Tollmien[18]. Wavelength $\lambda = 2\pi/\alpha$.

succeeded in providing it in about 1940. Convincing success came after these research workers constructed a wind tunnel of extremely low intensity of turbulence and used it for the verification of the stability theory. The neutral frequencies measured by Schubauer and Skramstad are shown plotted in Fig. 5, and it is seen that agreement between theory and experiment is excellent.

A clear idea about the amplification of unstable, harmonic perturbations, as they are postulated in the stability theory, can be formed with reference to the photographs shown in Fig. 6. These have been obtained by E. Eckert and his co-workers[17] by the use of an interferometer. They represent the convective stream forming on a heated vertical plate.

The beautiful experimental confirmation of the



(1) Normal aerofoil N.A.C.A. 0009.
(2) Laminar flow aerofoil N.A.C.A. 66-0009.
(3) Flat plate.
(*a*) Drag coefficient against Reynolds number.
(*b*) Pressure distribution at zero angle of incidence; $c_p = (p - p_\infty)/\frac{1}{2}\rho V^2$, pressure coefficient.

FIGURE 8. Drag coefficient and pressure distribution of a laminar flow aerofoil and a normal aerofoil.

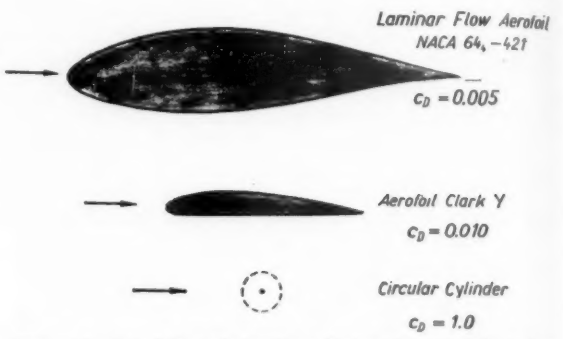
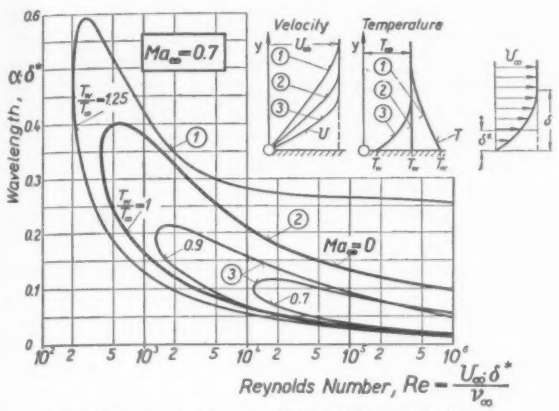


FIGURE 9. Aerofoils and circular cylinder with equal drag, from R. T. Jones[74].

stability theory supplied by Schubauer and Skramstad mentioned earlier, remained unknown in Germany until 1947 owing to the war. Nevertheless, and before that time, we had continued with the further development of the stability theory. During the course of this work it became possible to clarify further related questions, such as, for example, the influence of pressure gradient and suction on transition.

The *pressure gradient* which maintains the flow along the wall always exerts an important influence on stability and it is possible to establish the rule that a favourable pressure gradient highly stabilises the flow and an adverse pressure gradient highly de-stabilises it. The diagram in Fig. 7 shows plots of the curve of neutral stability for a boundary layer with a favourable and for one with an adverse pressure gradient. It is seen that the range of amplified frequencies is much greater and that the critical Reynolds number is considerably lower when the pressure rises downstream than in the case when the pressure falls. That this must be so follows from Tollmien's "point-of-inflexion criterion" of the theory of stability[18] which asserts that laminar velocity profiles with a point-of-inflexion exhibit much lower limits of stability than those without a point-of-inflexion. Since, as shown in Fig. 7, the laminar velocity profiles which correspond to an adverse pressure gradient always do, but those in favourable pressure gradients do not, possess a point-of-inflexion, it follows that this point-of-inflexion criterion is equivalent to the rule that a decrease in pressure in the downstream direction stabilises the flow. It follows also at once, but only as a first rough approximation, that the point of instability in the boundary layer lies close to the pressure minimum on the body.

The above highly stabilising influence exerted by the pressure gradient is utilised as an underlying physical principle for laminar flow aerofoils which became known shortly before the Second World War. The essence of a laminar flow aerofoil lies in the circumstance that its drag coefficient can be considerably reduced, if it is designed to possess a long stretch of laminar boundary layer, because the skin friction is much smaller in laminar than in turbulent flow. This result is achieved by displacing the section of maximum thickness in the downstream direction which causes the point of minimum pressure equally to move downstream. Fig. 8



(1) Heat transfer from wall to fluid (destabilising).
(2) No heat transfer (adiabatic wall).
(3) Heat transfer from fluid to wall (stabilising).

FIGURE 10. Curves of neutral stability for the laminar boundary layer with heat transfer (stability theory), theory from Lees and Lin[23]. Wavelength $\lambda = 2\pi/\alpha$.

shows the pressure distributions and the drag coefficient for two aerofoils at zero incidence, one of which is a normal one which has its maximum thickness at $x/c = 0{\cdot}3$, whereas the second is a laminar one with its maximum thickness at $x/c = 0{\cdot}45$. Owing to the downstream displacement of the point of maximum thickness, the point of minimum pressure has been moved rearwards by a considerable distance. Since the point of transition lies close to that of pressure minimum, as already stated earlier, the length of the laminar stretch of the boundary layer has now become considerably increased and this has caused the drag coefficient to fall appreciably. It can be inferred from Fig. 8 that the drag of the laminar flow aerofoil N.A.C.A. 66-009 is about half of that for the normal aerofoil N.A.C.A. 0009.

Figure 9 gives a good idea of the extraordinarily high aerodynamic efficiency of such a thoroughbred aerofoil. The figure shows a laminar flow aerofoil, an ordinary aerofoil, and a circular cylinder (wire) whose relative sizes have been so chosen as to ensure equal drag at the same speed. The laminar flow aerofoil has a drag coefficient of $c_D = 0{\cdot}005$, the ordinary aerofoil one of $c_D = 0{\cdot}010$. The circular cylinder with $c_D = 1{\cdot}00$ has a diameter equal to 1/200 of the chord length of the laminar flow aerofoil and 1/100 of that of the ordinary aerofoil.

It might be useful to recall at this point that the first announcement about the laminar flow aerofoils occurred in this country when G. W. Lewis (N.A.C.A.) described them in his Wilbur Wright Memorial Lecture in 1939[19]. Simultaneously but independently, H. Doetsch[20] carried out similar investigations in Germany. The connection between the behaviour of laminar flow aerofoils and stability theory was at once recognised in Germany in full measure, because we succeeded in considerably developing the theory in the period between 1930 and 1940[21, 22], in spite of the fact that it aroused serious doubts in the minds of some research workers outside Germany.

Some time later, L. Lees and C. C. Lin[23] extended the theory of stability to include compressible laminar boundary layers. In this case then appears an additional important parameter, namely that connected with the heat transfer at the wall. When the wall is adiabatic, the influence of compressibility alone on stability turns out to be actually very small, which means that the numerical value of the critical Reynolds number for the compressible case differs only slightly from that for the incompressible case. However, if the wall transfers heat the stability of the boundary layer becomes affected to a high degree. The corresponding curves of neutral stability are shown in Fig. 10. They have been plotted for different values of the ratio of the wall temperature, T_w, to the free-stream temperature T_∞. Here $T_w/T_\infty > 1$ signifies that heat is transferred from the wall to the fluid, and $T_w/T_\infty < 1$, that heat is transferred from the fluid to the wall. The diagram shows that wall cooling (extraction of heat from the fluid) stabilises the flow (like a favourable pressure gradient), but that the opposite is true about wall heating. This result of the stability theory is also in excellent agreement with experiments.

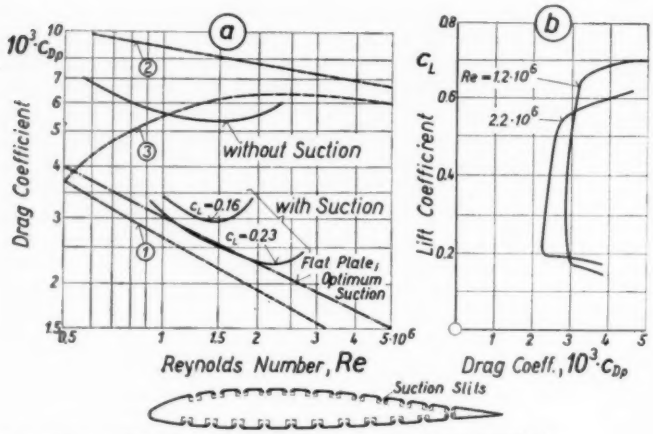
The theory of stability has been successfully applied in many other cases, as for example, for the flow on a curved wall. According to H. Goertler[24] unstable flows then develop standing waves whose axes are parallel to the main flow, somewhat in the manner of those first discovered by G. I. Taylor[25] between two concentric rotating cylinders, when the inner cylinder rotates and the outer cylinder is at rest.

I have given a survey of the whole field of "Transition" in a contribution to the *Encyclopedia of Physics*[76].

3. Boundary Layer Control

Problems of boundary layer control constitute another branch of boundary layer research in which theoretical developments as well as experimental investigations have led to surprising results. Boundary layer control consists in taking steps to influence the behaviour of the boundary layer, and hence of the whole flow, in some desired direction. The most important ways in which this can be done are the application of suction or blowing. In the former case it is usual to suck away some, mostly very little, of the fluid into the interior of the solid body. Thus it is possible to prevent separation from occurring, as shown by Prandtl in his first paper on boundary layer theory in 1904. By blowing, energy is implanted to the fluid in the boundary layer and this too aims at preventing separation. The investigation of boundary layer control has now developed into an important branch of boundary layer research. It has grown in volume during the past two or three decades and its practical importance has increased. That this is so can be inferred from the fact that it is now intended to publish in England, under the editorship of Dr. G. V. Lachmann, a handbook on "Boundary Layer Control" with contributions from a large number of authors.

Both methods of boundary layer control, namely



(*a*) Drag coefficient against Reynolds number, $Re = Vc/\nu$.
(1) Flat plate, laminar flow.
(2) Flat plate, fully turbulent flow.
(3) Flat plate, partly laminar and partly turbulent flow.
(*b*) Lift coefficient against coefficient of profile drag.

FIGURE 11. Lift and drag of an aerofoil with boundary layer control by suction through slits, from Pfenninger[34].

suction and blowing, have been applied with great success to wings a long time ago in order to prevent separation at large angles of incidence and so to achieve an *increase in the maximum value of lift*. This was comprehensively reported on by A. Betz[26, 27] some twenty years ago. Later, it was established on the basis of experiments performed by J. Ackeret[28] and H. Holstein[29] that suction can also be used to advantage for the *reduction of drag*. We shall begin with a short account of this development, since the decrease in drag occurs as a consequence of the fact that the boundary layer remains laminar and is, therefore, connected with the stability considerations discussed in the preceding section.

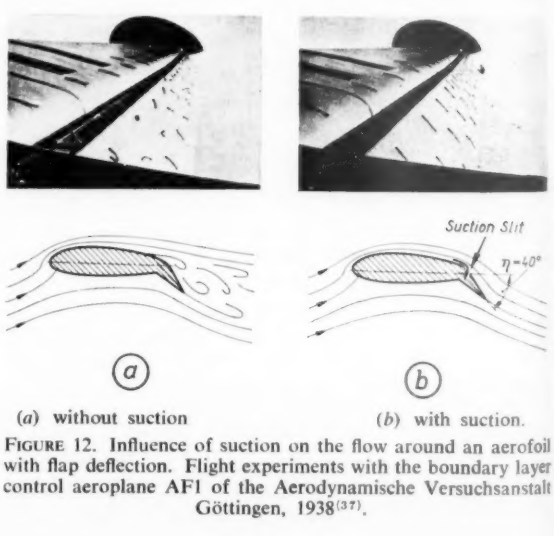
Reduction in drag

Prevention of transition by suction hinges on the fact that the boundary layer becomes thinner when suction is applied and is then less prone to become turbulent. It is, however, even more important to realise that even with equal thickness, a laminar boundary layer to which suction has been applied, possesses a markedly higher limit of stability than one without it. This was first discovered by K. Bussmann and H. Muenz[30] and J. Pretsch[31], and the work was later amplified by A. Ulrich[32]. The stabilising influence is particularly strong in the presence of continuous suction along the wall. This can be seen from the fact that the critical Reynolds number based on the displacement thickness from Fig. 5 for a flat plate without suction has the value $(U_\infty \delta^*/\nu)_{crit} = 420$, but that for a plate with continuous uniform suction is about 100 times larger. The stabilising effect of suction predicted by the theory has been confirmed experimentally by M. R. Head[33] in an excellent manner. W. Pfenninger[34] carried out detailed experiments on the reduction of drag by suction. Fig. 11 shows some of the results obtained for a wing section which was provided with a large number of suction slits. The curves of drag coefficient against Reynolds number for a series of values of the lift coefficient show that suction can lead to a considerable reduction in drag, particularly if it is borne in mind that the power expended on suction has been included in the evaluation of the drag coefficient. Fig. 11(*a*) contains a curve obtained with the aid of stability theory and marked "optimum suction." It represents the variation of the drag coefficient on a flat plate at zero incidence when suction is at the minimum which is just sufficient to prevent transition according to stability theory. The drag coefficients measured at low lift coefficient of the thin aerofoils now being considered come very close to these theoretical values.

In this connection it is necessary to draw attention to recent investigations into the fine structure of the laminar boundary layer along a wall provided with suction slits due to W. Wuest[43]. It turned out that a periodic distribution of slits, like the one shown in Fig. 11, gives rise to secondary flows in the shape of vortices whose axes are parallel to the slits. Such secondary flow considerably decreases the limit of stability of the boundary layer. Thus, it is seen that for that reason alone suction through individual slits is inferior to continuously distributed suction when it is desired to prevent transition.

Increase in maximum lift

When it is desired to increase the maximum lift of an aerofoil by the application of suction, it is necessary to prevent separation at large angles of incidence. Extensive experiments on this question were undertaken quite early, at the end of the twenties, by O. Schrenk[35] at the Aerodynamische Versuchsanstalt at Göttingen. The wind tunnel experiments on wings with flaps and suction turned out to be so successful that flight experiments appeared to be very promising. However, at that time, 1935, no German aircraft manufacturer was ready



(*a*) without suction (*b*) with suction.

FIGURE 12. Influence of suction on the flow around an aerofoil with flap deflection. Flight experiments with the boundary layer control aeroplane AF1 of the Aerodynamische Versuchsanstalt Göttingen, 1938[37].

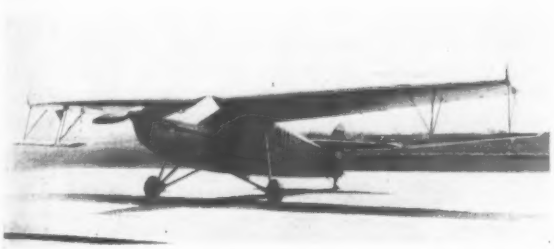


FIGURE 13. Aeroplane AF1 of the Aerodynamische Versuchsanstalt Göttingen with boundary layer control, 1938.

to build and test such an aeroplane, and therefore the Institute at Göttingen decided to undertake this by itself[37]. The Institute constructed and tested two such aeroplanes equipped with suction wings, the AF1 and the AF2; either of them was provided with relatively thick wings ($t/c=0{\cdot}18$ to $0{\cdot}20$) and with suction in the flap slit.

The photographs in Fig. 12 demonstrate that the application of suction through the slit between wing and flap can prevent separation which results in a large increase in lift. Fig. 12(*a*) shows that without suction, at a flap deflection angle of $\eta=40°$, the flow still adheres to the wing but that it is completely stalled at the flap. The application of suction, Fig. 12(*b*), causes the flow to re-attach itself to the flap and thus to give a large increase in lift.

Figure 13 shows a photograph of the Göttingen aeroplane AF1. In Fig. 14 some experimental flight results are given in the form of lift coefficient curves, for the two marks of the Göttingen aeroplanes and, for purposes of comparison, for the STOL aeroplane "Fieseler Storch" (Fi 156). The latter was equipped with a leading edge slit and a trailing edge flap, but with no suction. In agreement with wind tunnel results, the increase in lift coefficient attained by suction on the two Göttingen aeroplanes, AF1 and AF2, has proved to be very considerable ($c_{L\max}\simeq 4$). These values of maximum lift coefficient could not possibly be approached without suction.

Extensive experiments on the increase in lift by suction have been carried out in more modern times in Great Britain and the United States. In these experiments attention is centred on thin aerofoils. Here one might mention the work of E. D. Poppleton[38], N. Gregory and W. S. Walker[39], as well as that of R. C. Pankhurst[40]. When thin aerofoils are employed, suction in the flap slit ceases to be effective, because at large angles of incidence large suction peaks are formed on the upper side of the aerofoil and separation occurs near the leading edge. Consequently it was found necessary to adapt continuous suction on the suction side near the leading edge of the wing. Such continuous suction is advantageous, compared with suction through slits, because the requisite suction volumes become smaller. In this connection it becomes necessary to investigate the optimum distribution of suction along the surface of the wing in order to prevent separation with a minimum of suction volume. A contribution to this problem has recently been given by W. Pechau[41, 66].

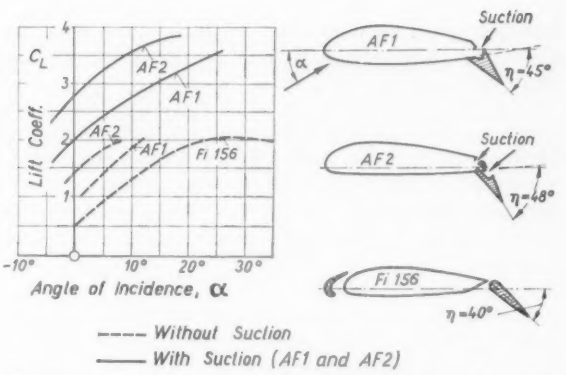


FIGURE 14. Lift of three STOL aeroplanes for full landing flap deflection (power-off). AF1 and AF2 boundary layer control aeroplanes of the Aerodynamische Versuchsanstalt Göttingen; Fi 156 aeroplane "Fieseler Storch."

The minimum required suction volume to avoid separation, expressed by the coefficient $c_{Q\min}$ could be determined on the basis of a new scheme of calculating the turbulent boundary layer with continuously distributed suction.

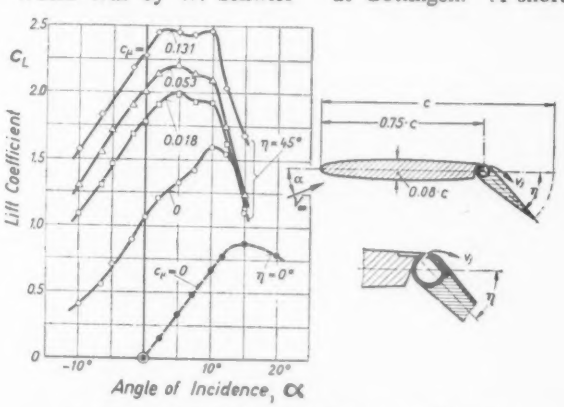
A. Raspet and his co-workers[42] carried out flight experiments on sailplanes with suction applied near the leading edge.

The other method of boundary layer control, *blowing*, is being applied in many different ways; for example, blowing near the leading edge, through the flap slot and at the trailing edge of the wing. The so-called momentum coefficient

$$c_\mu=\frac{\rho_j Q_j v_j}{\frac{1}{2}\rho_\infty V_\infty^2 S} \quad . \quad . \quad . \quad (1)$$

determines the effectiveness of the jet. Here ρ_j, Q_j and v_j, respectively, denote the density, discharge volume and discharge velocity of the jet, and ρ_∞, V_∞, respectively, denote the corresponding values for the stream flowing past the wing, which has the surface S.

The earliest systematic investigations into this complex of problems were performed during the Second World War by W. Schwier[44] at Göttingen. A short



c_μ = momentum coefficient of the jet, equation (1).
$c_\mu=0$, no blowing.

FIGURE 15. Increase of lift by blowing over the trailing edge flap. Experimental results of J. Williams[47].

summary of this work was given by Ph. Poisson-Quinton[45] when he described the extensive French experiments in this field.

Also in Great Britain in recent times a considerable amount of work was done on boundary layer control by blowing[46]. Fig. 15 shows the results of wind tunnel measurements on a wing with blowing over the trailing edge flap obtained by J. Williams[47]. The deflection of the flap alone increases the maximum lift coefficient from $c_{L\max}=0{\cdot}8$ to $1{\cdot}6$. The addition of blowing with $c_\mu=0{\cdot}13$ causes it to increase to $c_{L\max}=2{\cdot}5$.

Concluding this section, I wish to add that since the advent of jet propulsion, many problems of boundary layer control have appeared in a new light and that we are witnessing the birth of a new branch of applied aerodynamics. It rests on firm scientific foundations and its development has by no means been closed yet.

4. Thermal Boundary Layers

The boundary layer concept has proved fruitful also in relation to problems of heat transfer involving forced convection. When the flow velocity is reasonably high, the temperature field formed around the solid body becomes confined to a thin layer in the immediate neighbourhood of the body, the so-called thermal boundary layer. The temperature distribution in this thermal boundary layer then determines the rate of heat transfer between the solid body and the fluid.

Cases involving moderate flow velocities (incompressible flow) and moderate temperature differences between the wall and the stream can be calculated reasonably easily, as shown by E. Pohlhausen[48]. In such cases, the velocity boundary layer (velocity distribution) remains independent of the thermal boundary layer, because the small changes in the density and the viscosity of the fluid caused by the temperature differences can still be neglected.

When, however, the flow velocity becomes comparable with the velocity of sound, the phenomena which take place in the thermal boundary layer (as well as those in the velocity boundary layer) become considerably more complex. The frictional heat generated in the boundary layer may lead to such high temperatures that the density and the viscosity of the fluid in the boundary layer change to an important degree. Under those conditions, not only the velocity and temperature, but also the density and viscosity, vary from point to point. Even when the wall is completely insulated (adiabatic), the temperature in the boundary layer can become quite high owing to the evolution of frictional heat alone. As early as 1935, A. Busemann[49] was the first to study compressible boundary layers. The corresponding theory is considerably more difficult than that related to incompressible boundary layers, because a number of additional parameters must be taken into account. Apart from the Reynolds number, it is necessary to include the Mach number $Ma_\infty=U_\infty/a_\infty$ and the Prandtl number $\mathrm{Pr}=\mu c_p/k$, where c_p is the specific heat, k is the thermal conductivity of the gas and a_∞ the speed of sound. Further, the boundary condition prescribed for the temperature at the wall, corresponding to whether or not heat is transferred from or to it, is also very important.

The simplest problem concerning compressible boundary layers deals with the flat plate at zero incidence (*i.e.* with zero pressure gradient). In this case the temperature along an adiabatic wall is constant, but higher than that in the free stream. In the laminar flow of air, the temperature increase becomes equal to

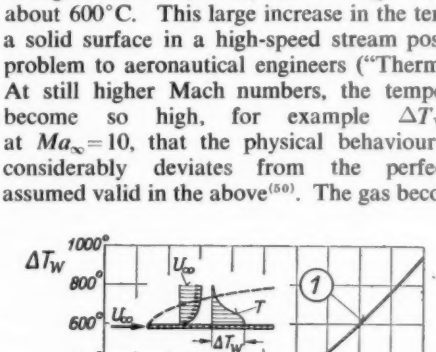
$$\Delta T_W=0{\cdot}17Ma_\infty{}^2T_\infty, \text{ (laminar)} \quad . \quad (2)$$

where T_∞ denotes the free-stream temperature. In turbulent boundary layers, the numerical factor in the equation changes to about 0·18. Compared with that, the temperature rise due to an equivalent isentropic compression would be

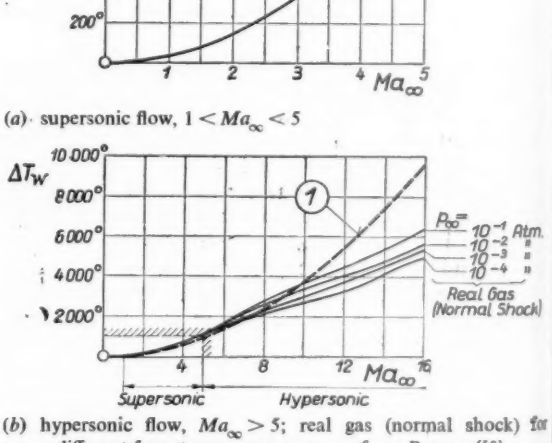
$$\Delta T_{ad}=0{\cdot}20Ma_\infty{}^2T_\infty,$$

that is, insignificantly more than that obtained by frictional heating. The temperature rise across a normal shock is approximately the same as that caused by friction.

Figure 16 shows a plot of the temperature increase at the wall calculated from the preceding formula. At transonic flow, $Ma_\infty=1$, it amounts to 40°C (72°F) in round figures, at supersonic flow, $Ma_\infty=2$, it is already as high as 150°C (270°F) and at $Ma_\infty=4$ it amounts to about 600°C. This large increase in the temperature of a solid surface in a high-speed stream poses a serious problem to aeronautical engineers ("Thermal barrier"). At still higher Mach numbers, the temperature rises become so high, for example $\Delta T_W\simeq 4{,}000$°C at $Ma_\infty=10$, that the physical behaviour of the gas considerably deviates from the perfect-gas laws assumed valid in the above[50]. The gas becomes dissoci-



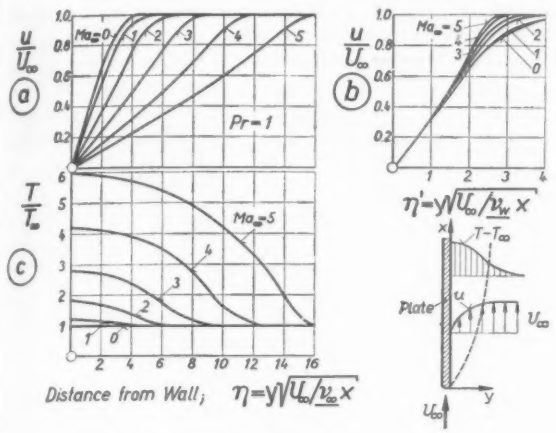
(*a*) supersonic flow, $1<Ma_\infty<5$



(*b*) hypersonic flow, $Ma_\infty>5$; real gas (normal shock) for different free stream pressures, p_∞, from Pearson[50].

$\Delta T_W=T_W-T_\infty$ = temperature increase of a flat plate against a free stream flow with temperature T_∞. Free stream temperature $T_\infty=222$°K; curve (1) for ideal gas, from equation (2).

FIGURE 16. Aerodynamic heating of a flat plate.



(*a*) and (*b*) velocity distribution.
(*c*) temperature distribution.
ν_∞ = kinematic viscosity of free stream flow.
ν_w = kinematic viscosity at the wall.

FIGURE 17. Compressible laminar boundary layer on an insulated flat plate for different Mach numbers Ma_∞, Prandtl number Pr = 1.

ated and even ionised and the actual temperature rises do not reach the magnitudes indicated by the preceding formulae. The latter can be inferred with reference to the curves p_∞ = constant in Fig. 16(*b*). In the domain of *supersonic flow* ($1 < Ma_\infty < 5$), the actual temperature rises are substantially those of a perfect gas (Fig. 16(*a*)), whereas the domain in which large deviations make themselves felt has now become known by the name of *hypersonic flow* ($Ma_\infty > 5$), Fig. 16(*b*).

During the twenty years which followed the pioneering paper by A. Busemann and the lecture delivered to the Volta Congress by Th. von Kármán[51] in 1935, the theory of laminar, compressible boundary layer flow underwent a period of intensive development. An outstanding, comprehensive account of this development was given some time ago by A. D. Young[52]. To give an idea of the results of this theory, it might be useful to consider one more typical example, namely one which concerns itself with the temperature distribution in the interior of the boundary layer.

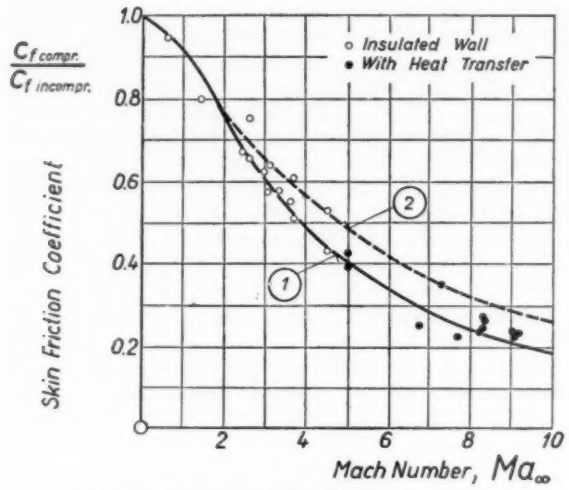
Figure 17 shows, again for the case of an adiabatic flat plate at zero incidence, the velocity distributions and the temperature distributions in the boundary layer for Mach numbers $Ma_\infty = 0$ to 5. In Fig. 17(*a*) and Fig. 17(*c*) the transverse co-ordinate y was here made dimensionless with the longitudinal co-ordinate x (distance from leading edge) and the constants of the external flow: free-stream velocity U_∞ and viscosity ν_∞. The wall temperatures implied in Fig. 17(*c*) supply a measure of the temperature rise due to frictional heating, and correspond to Fig. 16. One essential result is clearly apparent, namely that compressibility exerts only a minor influence on the boundary layer up to about $Ma_\infty = 1$, but at supersonic speeds ($1 < Ma_\infty < 5$) the boundary layer thickens by a large amount. At $Ma_\infty = 5$ the boundary layer thickness, and hence the thermal layer thickness, have become larger by a factor of five compared with incompressible flow ($Ma_\infty = 0$). However, this increase owing to the effect of the Mach number is due largely to the frictional temperature increase in the strata adjacent to the wall and to the consequent volume expansion. That this is so can be demonstrated by introducing the fluid properties near the wall instead of those in the free stream. If the transverse co-ordinate is made dimensionless with the kinematic viscosity at the wall ν_w*, as shown in Fig. 17(*b*), the velocity distributions for the whole Mach number range $Ma_\infty = 0$ to 5 nearly coalesce into one curve. In other words, the most essential difference between a compressible and an incompressible boundary layer consists in the fact that, in the former, frictional heat changes the density and viscosity of the fluid near the wall and that the values of these properties in the vicinity of the wall largely determine the flow. The boundary layer also behaves in the same general way in other cases, such as when the wall is heated or cooled. In particular, the same can be said about the friction and heat transfer coefficients at the wall. A. H. Shapiro[53] first drew attention to the remarkable relation that the friction coefficient, the Nusselt number, the velocity, and temperature profiles in the boundary layer remain nearly independent of the Mach number when the latter is smaller than about 5, on condition that the thermal properties of the fluid are evaluated at the wall.

Th. von Kármán[51] made an intuitive use of this important relationship when he delivered his lecture to the Volta Congress in 1935, that is at a time when it had, naturally, not yet been discovered. He used it to estimate the effect of the Mach number on the skin friction coefficient of a flat plate in laminar flow. von Kármán came then to the conclusion that the laminar skin-friction coefficient hardly depends on the Mach number when the plate is adiabatic. It decreases by about 15 per cent of its incompressible value only for a change in Mach number from 0 to 5. Later calculations[54, 55] confirmed von Kármán's estimate.

The increase in boundary layer thickness in compressible flow exerts a remarkable influence on the effect of roughness elements in such layers. According to P. F. Brinich[56] the effect produced by a single roughness element, such as a tripping wire, decreases with increasing Mach number in laminar, compressible flow. In the presence of a compressible, turbulent boundary layer and in the case of distributed roughness, the skin friction of a rough plate can be calculated in a simple manner, as shown by Liepmann and Goddard[57], from the decrease in the density of the gas near the wall which is produced by heating the wall.

In the study of compressible, turbulent boundary layers, it is up to the present time only possible to make predictions when the theory is reinforced by empirical data. In other words it is necessary to depend largely on experimental results. The friction coefficient of a flat plate with a turbulent boundary layer depends much more strongly on the Mach number than that of a laminar layer. Some results of American measurements on the variation of the skin friction coefficient of a flat

*We have $\sqrt{(\nu_w/\nu_\infty)} = T_w/T_\infty$ approximately.



(1) Insulated wall, theory Wilson[60].
(2) With heat transfer, theory van Driest[59].

FIGURE 18. Skin friction coefficient of a flat plate in compressible turbulent flow against Mach number.

plate with Mach number are seen plotted in Fig. 18[58]. According to these, when the wall is adiabatic, the skin friction coefficient decreases to about 40 per cent of the incompressible value at $Ma_\infty = 5$, and to about 20 per cent at $Ma_\infty = 10$. The transfer of heat has little effect on this coefficient as seen from measurements and from the two theoretical curves due to van Driest[59] and Wilson[60].

5. Three-Dimensional Boundary Layers

In this last section we propose to discuss some problems of boundary layer research whose physical nature is considerably more complex than that of the preceding sections. All the examples considered so far involved so-called two-dimensional flow, that is problems in which the velocity is given by two components each of which depends on two space co-ordinates only. For example on a wing of infinite span, the boundary layer is independent of the co-ordinate along the span, and there is no velocity component along the span.

By contrast, in engineering applications one often encounters problems in which the boundary layer is three-dimensional. An important case is that of a rotating body. In such cases, the centrifugal forces give rise to additional effects in the boundary layer and these generally lead to the appearance of *secondary flow*. A well-known example of this kind occurs in a cup of tea in which vigorous stirring produces secondary flow near the bottom and causes all tea leaves to agglomerate in the centre of the bottom.

The following few examples will show that boundary layer theory can contribute to an understanding of these complicated flow phenomena.

Swept wings

The case of swept wings affords a celebrated example of this class of phenomena in aerodynamics. The first to draw attention to the advantages of sweeping the wings at near-sonic velocities was A. Betz in 1939. This occurred after A. Busemann[61] had drawn attention to such advantages of the swept wing at supersonic speeds during the Volta Congress in Rome, 1935. The results of wind tunnel measurements performed at Göttingen in 1939 by H. Ludwieg[62] on a swept-back wing at high subsonic velocities are shown in Fig. 19. Betz rested his case on the premise that the velocity distribution on the wing is not determined by the flight velocity V, but its component $V\cos\Lambda$ normal to the leading edge. If this is true, it might be expected that sweepback will relegate to higher Mach numbers the effects of shock waves which occur on the wing at high subsonic velocities, thus causing large increase in drag. The polar diagrams contained in Fig. 19(*a*) for an unswept wing ($\Lambda = 0$), and in Fig. 19(*b*) for a swept wing ($\Lambda = 45°$), fully confirm this contention.

In this connection it might be mentioned that the preceding initial success was followed up in Germany, during the Second World War, by a thorough study of the aerodynamics of swept wings. In other countries the advantages of swept wings remained unnoticed until the end of the war; see here R. Smelt[63] and Th. von Kármán[72]. After the war, the swept wing soon became generally accepted.

The swept wing possesses several important disadvantages in addition to its strong points already mentioned. The former are first of all connected with the behaviour of its boundary layer. At large angles of incidence the outer parts of a swept wing show premature separation. This leads to large, unstable (tail-heavy) pitching moments as well as to loss of

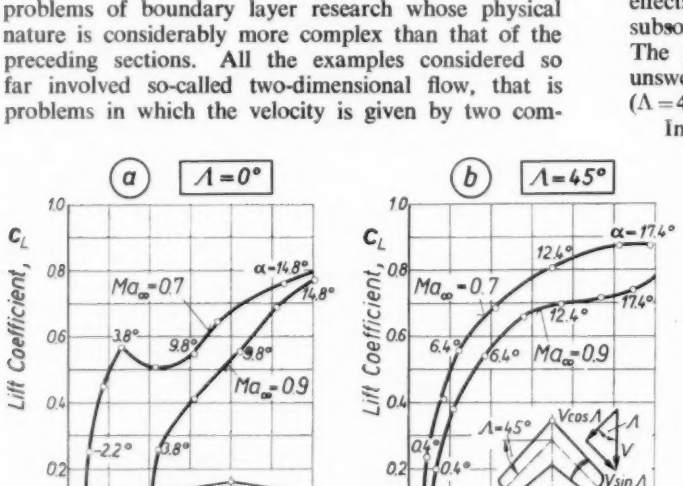
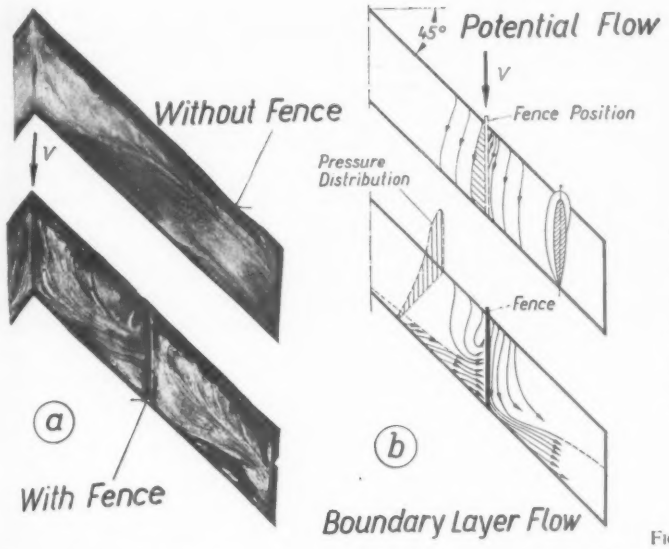
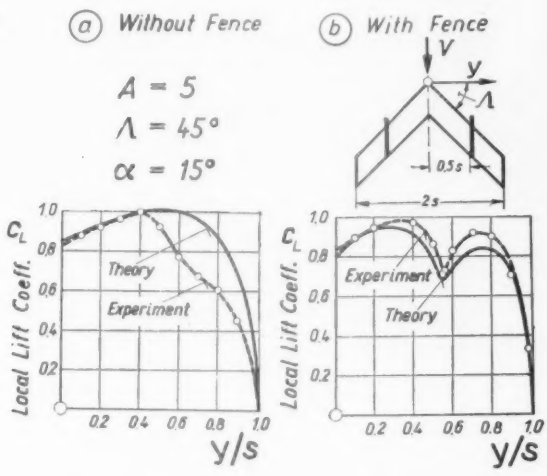


FIGURE 19. Lift and drag of a swept-back wing in transonic flow. Measurements of H. Ludwieg[62], Göttingen, 1939.



(*a*) Photographs of flow without and with boundary layer fence. Aspect ratio, $A=5$. Angle of incidence, $\alpha=12°$. (*b*) Schematic stream lines without and with boundary layer fence. Angle of sweep, $\Lambda=45°$. Reynolds number $\mathrm{Re}=Vc/\nu=4\cdot10^5$.

FIGURE 20. Flow investigations on a swept wing with boundary layer fence, from A. Das[65].



Reynolds number $\mathrm{Re}=Vc/\nu=4\cdot10^5$.

FIGURE 21. Spanwise lift distribution of a swept wing with boundary layer fence, from A. Das[65].

effectiveness in the outer parts of the flaps. The reasons for this unfavourable aerodynamic behaviour of the wing lie, first, in the increased loading of the outer wing sections, and this alone causes premature separation there. Secondly, this unfavourable behaviour is amplified by the fact that in the boundary layer the velocity component $V\sin\Lambda$ causes a movement of retarded fluid particles in the direction of the receding part of the wing. This transverse flow results in a large increase in the boundary layer thickness near the tips, which further leads to proneness to separation on the suction side of the wing.

It was first shown by W. Liebe[64] that these awkward features of swept wings can be eliminated or at least mitigated by the provision of a boundary layer fence on the upper side of the wing. Recently, one of my co-workers, A. Das[65, 66] has devoted himself to a thorough study of the behaviour of such boundary layer fences, both on swept and on delta wings. The first important result of this study was the recognition of the fact that boundary layer fences are rather ineffective on delta wings but very beneficial on swept wings. This is a consequence of the fact that on a delta wing the local angle of sweep is very small in the neighbourhood of the trailing edge where separation of the boundary layer begins. Furthermore, Das found that the essence of the action of a boundary layer fence does not so much consist in the prevention of transverse flow but, much more importantly, in the circumstance that the fence divides each wing into an inner and an outer part on which both transverse flow and separation may still be present, but to a reduced extent.

Figure 20 reproduces photographs which illustrate the action of a boundary layer fence on a swept-back wing of constant chord. Figs. 20(*a*) and (*b*) demonstrate that separation has been highly curtailed near the tip, and that, in addition, a new separation zone appears on the inner side of the fence. The appearance of this new separation zone can be understood at once when the potential flow on the swept wing is imagined. The streamlines of the flow are shown sketched in Fig. 20(*b*). Near the leading edge their direction is seen to deviate considerably from that in the free stream. The sharp-edged fence is placed inside this highly curved external flow and creates the separation zone in the same way as a plate standing at right angles to the stream.

The modifications introduced into the flow by the fence, naturally affect the lift distribution. This is illustrated in Fig. 21 which shows the lift distribution across the span of a swept-back wing provided with a fence at half-width. Without the fence (Fig. 21(*a*)), there is good agreement between the theoretical and the measured lift distribution near the root of the wing; near its tip the measured lift remains considerably below the predicted value owing to incipient separation. The results in Fig. 21(*b*) for the case with a fence show that now high lift values occur near the tips as well. However, near the fence there occurs a dip in the lift distribution owing to the separation zone present there. Das succeeded in calculating the spanwise lift distribution for the case with fence and obtained good agreement with measurements. This was achieved simply by assuming for the section near the fence the decreased value of the lift slope, $c_{L\infty}'=0\cdot4\,(2\pi)$, which is measured on separated aerofoils.

Turbo-machinery

The flow in the channels of turbine wheels, on propellers, fan rotors, and stators constitutes one more example of flows in which secondary motion in the boundary layer strongly affects the process. For

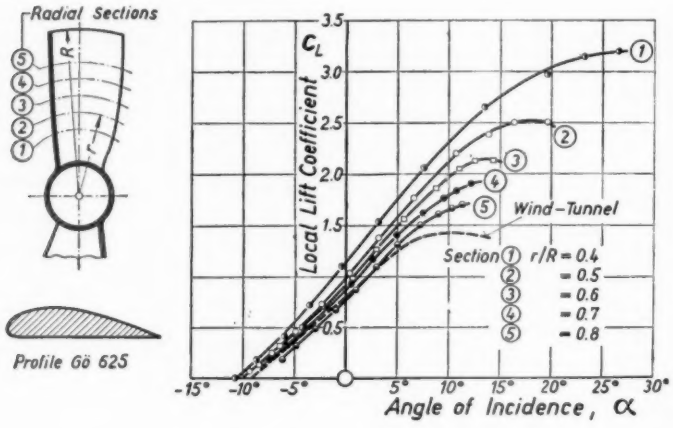


FIGURE 22. Local lift coefficient of a propeller blade at different radial sections (1) to (5), compared with a wind tunnel measurement, from H. Himmelskamp[67].

example, with a rotating propeller arm, the fluid particles in the boundary layer are acted upon by strong centrifugal forces which cause them to be thrown outwards. This is favourable for the creation of lift on propeller blades, because the boundary layer becomes much thinner as a consequence of the outward motion, and separates later, that is at much higher angles of incidence which means that the lift forces can be much greater. These phenomena, which are important for all kinds of turbo-machinery, have been thoroughly investigated by H. Himmelskamp[67] in his Göttingen thesis. The variation of the local lift coefficient c_L with angle of incidence α for several sections of a rotating propeller arm is plotted in Fig. 22. The corresponding curve obtained in a wind tunnel is also shown for the purpose of comparison, because in the latter case the action of centrifugal forces was absent. The maximum value of lift coefficient in the wind tunnel test was about 1·4, but the maximum value on the rotating propeller blade, reached at the innermost section, attained a value of $c_{L\max}=3{\cdot}2$. Thus it is seen that the increase in lift owing to the action of the centrifugal forces is very considerable.

At low Reynolds numbers, the presence of a centrifugal force has a strong influence on transition. It was shown in the Göttingen thesis by H. Muesmann[68] that, other things being equal, transition on a rotating aerofoil occurs at a lower Reynolds number than on a stationary one.

In recent times, boundary layer theory has found an important application in the solution of flow problems of cascades as they occur in turbo-machines. In extensive theoretical and experimental investigations with the aid of boundary layer theory a method has been established for the calculation of the aerodynamic coefficients of two-dimensional cascades and especially of their loss coefficients. I have recently given a survey on these investigations[70, 71], and the details of this method have been published in a paper by L. Speidel and N. Scholz[69].

6. Conclusions

If we take a survey of the developments in the five decades since the inception of boundary layer theory, we can, with Dryden[7], make the following statements:—

HISTORICAL DEVELOPMENT

During the *first decade* (1904-1914) which followed Prandtl's now classical paper of 1904, there appeared in all fewer than ten contributions to boundary layer theory, all having come from Prandtl and his post-graduate students. The average number of contributions, then, was less than one per annum.

Contributions from outside Göttingen did not appear until the *second decade* (1914-1924). There existed at that time three groups of contributors, namely at Göttingen, Aachen, and Delft (Holland). The first experimental verifications of boundary layer theory were obtained towards the end of this period.

During the *third decade* (1924-1934), boundary layer theory penetrated further into countries outside Germany. Furthermore, in that decade, Tollmien succeeded in taking the first successful step towards the creation of a theory of transition. At the same time, Ackeret and Schrenk at Göttingen carried out the first extensive investigations into boundary layer control and Stueper provided the first flight-measurements on boundary layers. The volume of boundary layer research had now increased to an average of five or six papers per annum. During this period Tollmien wrote the first comprehensive review of the subject in the "Handbuch der Experimentalphysik" (1931). Some years later Prandtl gave a more detailed review in Durand's "Aerodynamic Theory" (1935).

The beginning of the *fourth decade* (1934-1944) was marked by the Volta Congress which took place in Rome in 1935. In the year 1937, Melville Jones delivered the first Wright Brothers' Lecture in the United States on "Flight experiments on the boundary layer"[78]; Busemann and von Kármán pioneered the study of compressible boundary layers; H. L. Dryden and his co-workers, Schubauer and Skramstad, succeeded in providing an experimental verification of Tollmien's stability theory. The Second World War did not materially retard the research activities in this field. The number of published contributions had now increased to about fourteen in a year.

The *fifth decade* (1944-1954) brought with it a continued, steep increase in the volume of boundary layer research. During that decade the central position is occupied by the efforts to develop boundary layer theory for laminar and turbulent compressible boundary layers. A comprehensive review of the whole field of boundary layers was published in 1951[8]. Towards the end of this decade the number of published papers increased to something like 120 in one year.

CONCLUSIONS

In conclusion the following statements can be made: —

Prandtl's boundary layer theory originated from the intuition of a great scientist of genius and of world-wide significance, of a man who combined an unusual gift for fine observation with that for mathematical abstraction. It opened in an astonishing way the doors to problems which would surely never have been tackled by purely mathematical means.

In the period of over five decades, which elapsed from its inception, boundary layer theory has exerted a wide and exceedingly fruitful influence on almost all branches of fluid dynamics. Many neighbouring fields of fluid dynamics, such as, for example, convective heat and mass transfer, became amenable to quantitative study for the first time as a result of the application of boundary layer theory.

Now, it has become clear that boundary layer theory blasted new paths of development for the whole of fluid mechanics and one is certainly justified in regarding the instant of its discovery as the moment in which modern fluid mechanics was born.

The development of boundary layer theory, as it occurred in the first fifty years of its existence, provides a fascinating example of the birth of an idea, of its slow development by its creator and his students, of its at first hesitant acceptance by other research workers, and its triumphal, almost exponential growth owing to contributions from other scientists.

Now, after more than half a century, Prandtl's concept of the boundary layer has lost nothing of its fruitfulness. This is common with Lanchester's aerofoil theory. Both these theories provided solutions for an uncountable number of problems in fluid mechanics. One can confidently expect that in the future their contribution to the solution of still outstanding problems of fluid flow will be no less than it has been in the past.

ACKNOWLEDGMENT

For the English translation of this lecture the author is very much indebted to Professor J. Kestin, Brown University, Providence, R.I., U.S.A.

REFERENCES

1. VON KÁRMÁN, TH. (1957). First Lanchester Memorial Lecture: Lanchester's Contributions to the Theory of Flight and Operational Research. *Journal of the Royal Aeronautical Society*, 62, pp. 80-93, February 1958.
2. COLLAR, A. R. (1958). Second Lanchester Memorial Lecture: Aeroelasticity—Retrospect and Prospect. *Journal of the Royal Aeronautical Society*, 63, pp. 1-15, January 1959.
3. PRANDTL, L. (1927). The Generation of Vortices in Fluids of Small Viscosity. 15th Wilbur Wright Memorial Lecture. *Journal of the Royal Aeronautical Society*, 31, p. 720, 1927. *See also*: Die Entstehung von Wirbeln in einer Flüssigkeit mit kleiner Reibung. Zeitschr. Flugtechn. Motorluftsch. 18, S. 489-496, 1927.
4. PRANDTL, L. (1904). Ueber Flüssigkeitsbewegung bei sehr kleiner Reibung. *Proceedings of the Third International Mathematics Congress*, Heidelberg, 1904. Reprinted in *Vier Abhandlungen zu Hydro- und Aerodynamik*, Göttingen, 1927, N.A.C.A. Tech. Memo 452, 1928.
5. LANCHESTER, F. W. (1936). The Part Played by Skin Friction in Aeronautics. *Journal of the Royal Aeronautical Society*, Vol. 41, pp. 68-131, 1937.
6. PRANDTL, L. (1935). The Mechanics of Viscous Fluids. In W. F. Durand, *Aerodynamic Theory*, 111, pp. 34-208, 1935.
7. DRYDEN, H. L. (1955). Fifty Years of Boundary Layer Theory and Experiment. *Sciences*, 121, pp. 375-380, 1955.
8. SCHLICHTING, H. (1951). *Grenzschicht-Theorie*. 1st ed. Karlsruhe, 1951, 3rd ed., 1958. English translation by J. Kestin: *Boundary Layer Theory*, London and New York, 1955.
9. REYNOLDS, O. *Phil. Trans. Roy. Soc.*, 1883, or Collected Papers, II, 51. *See also* Scientific Papers II, 1883, and also: On the Dynamic Theory of Incompressible Viscous Fluids and the Determination of the Criterion. *Phil. Trans. Roy. Soc.*, 1895.
10. LORD RAYLEIGH. Scientific Papers I, 474, 1880; III, 17, 1887; IV, 197, 1913. *See also*: On the Stability of Certain Fluid Motions. *Proc. London Math. Soc.*, 11, 57, 1880, and 19, 67, 1887. Scientific Papers I, 474, and III, 17. *See also*: Scientific Papers IV, 203, 1895, and VI, 197, 1913.
11. PRANDTL, L. Bemerkungen über die Entstehung der Turbulenz. *ZAMM*, 1, pp. 431-436, 1921. *See also*: *ZAMM*, 11, pp. 407-409, 1931.
12. TIETJENS, O. Beiträge zur Entstehung der Turbulenz. Thesis, Göttingen, 1922, and *ZAMM*, 5, pp. 200-217, 1925.
13. HEISENBERG, W. (1924). Ueber Stabilität und Turbulenz von Flüssigkeitsströmen. *Ann. d. Physik*, 24, p. 577, 1924.
14. TOLLMIEN, W. Ueber die Entstehung der Turbulenz. 1. Mitteilung, Nachr. Ges. Wiss. Göttingen, Math. Phys. Klasse 21-44, 1929; English translation in N.A.C.A. T.M. 609, 1931.
15. SCHLICHTING, H. (1935). Amplitudenverteilung und Energiebilanz der kleinen Störungen bei der Plattenströmung. Nachr. Ges. Wiss. Göttingen, Math. Phys. Klasse, Fachgruppe I, 4, 47-78, 1935 and N.A.C.A. T.M. 1265, 1950.
16. SCHUBAUER, G. B. and SKRAMSTAD, H. K. Laminar-Boundary Layer Oscillations and Stability of Laminar Flow. National Bureau of Standards Research Paper 1772. Reprint of a confidential N.A.C.A. Report dated April 1943 (later released as N.A.C.A. War-time Report W-8), and *Journal of the Aeronautical Sciences*, 14, 69, 1947; *see also* N.A.C.A. Report 909, 1948.
17. ECKERT, E. R. G., SOEHNGEN, E. and SCHNEIDER, F. J. (1955). Studien zum Umschlag laminar-turbulent der freien Konvektions-Strömung an einer senkrechten Platte. Anniversary volume *Fünfzig Jahre Grenzschichtforschung*, edited by H. Görtler and W. Tollmien, Braunschweig, pp. 407-418, 1955.
18. TOLLMIEN, W. Ein allgemeines Kriterium der Instabilität laminarer Geschwindigkeitsverteilungen. Nachr. Ges. Wiss. Göttingen, Math. Phys. Klasse, Fachgruppe I, 1, 79-114, 1935; English translation in N.A.C.A. T.M. 792, 1936.
19. LEWIS, G. W. (1939). Some Modern Methods of Research in the Problem of Flight. *Journal of the Royal Aeronautical Society*, 43, pp. 771-798, 1939.
20. DOETSCH, H. (1940). Untersuchungen an einigen Profilen mit geringem Widerstand im Bereich kleiner c_a-Werte. Jb. d. dt. *Luftfahrtforschung*, I, 54-57, 1940.
21. SCHLICHTING, H. (1940). Ueber die theoretische Berechnung der kritischen Reynoldsschen Zahl einer Reibungsschicht in beschleunigter und verzögerter Strömung. Jb. d. dt. *Luftfahrtforschung*, I, 97-112, 1940.
22. SCHLICHTING, H. and ULRICH, A. Zur Berechnung des Umschlages laminar-turbulent. Jb. d. dt. *Luftfahrtforschung*, I, 8-35, 1942. 1940 prize essay of the Lilienthal-Society for Aeron. Research. Complete text in *Bericht S 10 of the Lilienthal Gesellschaft*, 75-135, 1940.
23. LEES, L. and LIN, C. C. (1946). Investigation of the Stability of the Laminar Boundary Layer in a Compressible Fluid. N.A.C.A. T.N. 1115, 1946.
24. GÖRTLER, H. Ueber eine dreidimensionale Instabilität laminarer Grenzschichten an konkaven Wänden. Nachr. Wiss. Ges. Göttingen, Math. Phys. Klasse. New series 2, No. 1, 1940. *See also*: *ZAMM*, 21, 250-252, 1941.
25. TAYLOR, G. I. (1923). Stability of a Viscous Liquid Con-

tained between Two Rotating Cylinders. *Phil. Trans.* A 223, 298, 1923.

26. BETZ, A. (1939). Beeinflussung der Reibungsschicht und ihre praktische Verwertung. Schriften d. dt. Akademie d. *Luftfahrtforschung*, No. 49, pp. 51-70, 1939.
27. BETZ, A. (1942). Neuere Ergebnisse der Auftriebsbeeinflussung von Flügeln. Schriften d. dt. Akademie d. *Luftfahrtforschung*, Berlin, 1942.
28. ACKERET, J., RAS, M. and PFENNINGER, W. (1941). Verhinderung des Turbulentwerdens einer Reibungsschicht durch Absaugung. *Naturwissenschaften*, 622, 1941. *See also*: *Helv. phys.* Acta, 14, 323, 1941.
29. HOLSTEIN, H. (1940). Messungen zur Laminarhaltung der Grenzschicht an einem Flügel. Lilienthal-Report, S 10, 17-27, 1940.
30. BUSSMANN, K. and MÜNZ, H. (1942). Die Stabilität der laminaren Reibungsschicht mit Absaugung. Jb. d. dt. *Luftfahrtforschung*, I, 36-39, 1942.
31. PRETSCH, J. (1942). Umschlagbeginn und Absaugung. Jb. d. dt. *Luftfartforschung*, I, 1-7, 1942.
32. ULRICH, A. (1944). Theoretische Untersuchungen über die Widerstandsersparnis durch Laminarhaltung mit Absaugung. Schriften d. dt. Akademie d. *Luftfahrtforschung*, 8 B, No. 2, 1944.
33. HEAD, M. R. (1955). The Boundary Layer with Distributed Suction. A.R.C. R. & M. 2783, 1955.
34. PFENNINGER, W. Untersuchungen über Reibungsverminderungen an Tragflügeln, insbesondere mit Hilfe von Grenzschichtabsaugung. Reports of the Aero Inst. ETH, Zürich, No. 13, 1946. *See also*: *Journal of the Aeronautical Sciences*, 16, 227-236, 1949; N.A.C.A. T.M. No. 1181, 1947.
35. SCHRENK, O. Tragflügel mit Grenzschichtabsaugung. *Luftfahrtforschung*, 2, pp. 49-62, 1928; Zeitschr. f. Flugt. u. Motorluftsch., 22, pp. 259-264, 1931.
36. SCHRENK, O. (1935). Versuche mit Absaugeflügeln. *Luftfahrtforschung*, 12, pp. 10-27, 1935.
37. STÜPER, J. Flight Experiences and Tests on two Airplanes with Suction Slots. N.A.C.A. T.M. 1232, 1950. Translation of ZWB FB 1821, 1943.
38. POPPLETON, E. D. (1955). Boundary-Layer Control for High Lift by Suction at the Leading-Edge of a 40 Degree Swept-Back Wing. A.R.C. R. & M. 2897, 1955.
39. GREGORY, N. and WALKER, W. S. (1955). Wind-Tunnel Tests on the N.A.C.A. 63A009 Aerofoil with Distributed Suction over the Nose. A.R.C. R. & M. 2900, 1955.
40. PANKHURST, R. C., RAYMER, W. G. and DEVEREUX, A. N. (1953). Wind-Tunnel Tests of the Stalling Properties on an 8 per cent Thick Symmetrical Section with Nose Suction through a Porous Surface. A.R.C. R. & M. 2666, 1953. *See also*: R. C. Pankhurst: Recent British Work on Methods of Boundary Layer Control. Boundary Layer Symposium at National Physical Laboratory, 1955.
41. PECHAU, W. Ein Näherungsverfahren zur Berechnung der ebenen und rotationssymmetrischen turbulenten Grenzschicht mit beliebiger Absaugung oder Ausblasung. Jahrb. d. Wiss. Ges. f. Luftf., pp. 82-92, 1958. *See also*: H. Schlichting and W. Pechau: Auftriebserhöhung von Tragflügeln durch kontinuierlich verteilte Absaugung. *Z. f. Flugw.* 7, No. 5, pp. 113-119, 1959. 75th Anniversary Volume for Cl. Dornier.
42. RASPET, A., CORNISH, J. J. and BRYANT, G. D. (1956). Delay of the Stall by Suction through Distributed Perforations. *Aero. Eng. Rev.*, 15, No. 8, pp. 32-39, 1956.
43. WUEST, W. (1957). Periodische Absaugegrenzschichten. Grenzschichtforschung, Symposium on Boundary Layer Research, Freiburg, Edited by H. Görtler, 1958.
44. SCHWIER, W. (1942). Versuche zur Auftriebssteigerung durch Ausblasen von Luft an einen Profil von 12% Dicke mit verschiedenen Klappenformen. Zentrale f. wiss. Berichtswesen, Berlin-Adlershof FB 1658, 1942.
45. POISSON-QUINTON, PH. (1956). Einige physikalische Betrachtungen über das Ausblasen an Tragflügeln. *WGL-Jahrbuch*, pp. 29-51, 1956.
46. WILLIAMS, J. (1958). British Research on Boundary Layer Control for High Lift by Blowing. *Z. f. Flugwiss.* 6, pp. 143-150, 1958.
47. WILLIAMS, J. and ALEXANDER, A. J. (1958). Pressure-Plotting Measurements on an 8 per cent Thick Aerofoil with Trailing Edge Flap Blowing. A.R.C. R. & M. 3087, 1958.
48. POHLHAUSEN, E. (1921). Der Wärmeaustausch zwischen festen Körpern und Flüssigkeiten mit kleiner Reibung und kleiner Wärmeleitung. *ZAMM*, 1, 115-121, 1921.
49. BUSEMANN, A. (1935). Gasströmung mit laminarer Grenzschicht entlang einer Platte. *ZAMM*, 15, pp. 23-25, 1935.
50. PEARSON, E. P. (1957). Introductory Remarks Concerning some Aspects of Hypersonic Research and Research Facility Requirements. Paper presented to AGARD Wind Tunnel Panel Meeting, Scheveningen, Holland, July 1957.
51. VON KÁRMÁN, TH. and TSIEN, H. S. Boundary Layer in Compressible Fluids. *Journal of the Aeronautical Sciences*, 5, 227-232, 1938. *See also*: Th. von Kármán, Report on the Volta Congress, Rome, 1935.
52. YOUNG, A. D. (1953). Section on "Boundary Layers" in *Modern Developments in Fluid Dynamics, High Speed Flow*, edited by L. Howarth, Vol. I, 375-475. Clarendon Press, 1953.
53. SHAPIRO, A. H. (1954). *The Dynamics and Thermodynamics of Compressible Fluid Flow*. Vol. II. Ronald Press, New York, 1954.
54. CROCCO, L. (1941). Sullo strato limite laminare nei gas lungo una lamina plana. Rend. Mat. Univ. Roma, V 2, 138, 1941.
55. HANTZSCHE, W. and WENDT, H. (1940). Zum Kompressibilitätseinfluss bei der laminaren Grenzschicht der ebenen Platte. Jb. d. dt. *Luftfahrtforschung*, I, 517-521, 1940.
56. BRINICH, P. F. (1954). Boundary-Layer Transition at Mach 3·12 with and without Single Roughness Elements. N.A.C.A. T.N. No. 3267, 1954.
57. LIEPMANN, H. W. and GODDARD, F. E. (1957). Note on the Mach Number Effect upon the Skin Friction of Rough Surfaces. *Journal of the Aeronautical Sciences*, 24, 784, 1957.
58. HILL, F. K. (1956). Boundary-Layer Measurements in Hypersonic Flow. *Journal of the Aeronautical Sciences*, 23, 35-42, 1956.
59. VAN DRIEST, E. R. (1951). Turbulent Boundary Layer in Compressible Fluids. *Journal of the Aeronautical Sciences*, 18, 145-160, 1951.
60. WILSON, R. E. (1950). Turbulent Boundary-Layer Characteristics at Supersonic Speeds—Theory and Experiment. *Journal of the Aeronautical Sciences*, 17, 585-594, 1950.
61. BUSEMANN, A. (1935). Aerodynamischer Auftrieb bei Ueberschallgeschwindigkeit. *Proc. Volta Congress*, Rome, pp. 328-360, 1935.
62. LUDWIEG, H. Pfeilflügel bei hohen Geschwindigkeiten. Report No. 127 der Lilienthal-Gesellschaft für Luftfahrtforschung, 1940. *See also*: AVA-Bericht 39/H/18, December 1938, and A. Betz: *Naturwiss., V.D.I. Zeitschr.*, 92, 1950.
63. SMELT, R. (1946). A Critical Review of German Research on High Speed Airflow. *Journal of the Royal Aeronautical Society*, 50, 899-934, 1946.
64. LIEBE, W. (1952). Der Grenzschichtzaun. *Interavia*, 7, pp. 215-217, 1952.
65. DAS, A. (1959). Untersuchungen über den Einfluss von Grenzschichtzäunen auf die aerodynamischen Eigenschaften von Pfeil- und Deltaflügeln. Thesis, Braunschweig, 1959, *Zeitschr. f. Flugwiss.*, 7, pp. 227-242, 1959.
66. SCHLICHTING, H. (1958). Einige neuere Ergebnisse über Grenzschichtbeeinflussung. *Proceedings of the First International Congress of the Aeronautical Sciences*, Madrid, 1958. Pergamon Press, London, 1960.
67. HIMMELSKAMP, H. (1950). Profiluntersuchungen an einem umlaufenden Propeller. Mitteilungen a. d. Max-Planck-Institut für Strömungsforschung, Göttingen, No. 2, 1950.
68. MUESMANN, G. (1958). Zusammenhang der Strömungseigenschaften des Laufrades eines Axialgebläses mit denen eines Einzelflügels. *Zeitschr. f. Flugwiss.*, 6, 1958.
69. SPEIDEL, L. and SCHOLZ, N. (1957). Untersuchungen

über die Strömungsverluste in ebenen Schaufelgittern. *VDI-Forschungsheft*, 464, Series B, Vol. 23, 1957.

70. SCHLICHTING, H. Ergebnisse und Probleme von Gitteruntersuchungen. *Zeitschr. f. Flugwiss.*, 1, pp. 109-122, 1953, and VDI-Bericht, 3, pp. 7-21, 1955. English translation in *Journal of the Aeronautical Sciences*, 21, 163-178, 1954.
71. SCHLICHTING, H. (1959). Application of Boundary Layer Theory in Turbomachinery. *Jour. Basic Engineering*, Vol. 81, 1959; *see also Siemens Zeitschrift*, 33, 1959.
72. VON KÁRMÁN, TH. (1954). *Aerodynamics. Selected Topics in the Light of their Historical Development*. Cornell University Press, 1954.
73. PRANDTL, L. Neuere Ergebnisse der Turbulenzforschung. Zeitschr. *VDI*, 77, pp. 105-114, 1933. *See also*: H. Schlichting, Neuere Untersuchungen über die Turbulenzentstehung. *Die Naturwissenschaften*. pp. 376-381, 1934.
74. JONES, R. T. (1956). Some Recent Developments in the Aerodynamics of Wings for High Speeds. *Zeitschr. f. Flugwiss.*, 4, pp. 257-262, 1956.
75. ZAAT, J. A. (1958). Numerische Beiträge zur Stabilitätstheorie der Grenzschichten. Grenzschichtforschung, Symposium on Boundary Layer Research, Freiburg. Edited by H. Görtler, pp. 127-139, 1958.
76. SCHLICHTING, H. (1959). Entstehung der Turbulenz. *Handbuch der Physik.—Encyclopedia of Physics*. Vol. VIII/1, Fluid Dynamics I. pp. 351-450. Springer, Berlin, 1959.
77. GÖRTLER, H. (Editor). *Grenzschichtforschung—Boundary Layer Research*. IUTAM Symposium Freiburg/Brsg., August 1957. Springer, Berlin, 1958.
78. JONES, B. M. (1938). Flight Experiments on the Boundary Layer. First Wright Brothers' Lecture, 1937. *Journal of the Aeronautical Sciences*, 5, pp. 81-101, 1938.

VOTE OF THANKS

MR. MASEFIELD: We have heard a most absorbing statement of the evolution of aerodynamic theory, and particularly developments in boundary layer research—during a most fruitful thirty years—a generation of flight.

Just as thirty years ago, Prandtl took us from the birth of flight over the first generation, now we have been brought up to date with the second thirty years.

I think we all congratulate Professor Schlichting on his English. I am sure we wish we could do half as well in any other than our Mother Tongue.

Now, according to custom, there is no discussion following this lecture, and I call upon Mr. Morien Morgan to propose a vote of thanks.

MR. M. B. MORGAN, C.B., F.R.Ae.S. (Scientific Adviser, Air Ministry): We have had the privilege of listening to a survey of boundary layer research by a scientist whose name is revered wherever aerodynamicists gather together. It is my pleasant duty to propose a vote of thanks to Professor Schlichting, who has come over from Brunswick in order to be with us this evening. I was going to say that he had flown over; that his journey was made short and pleasant by the aircraft designers' use of basic knowledge, of induced drag and boundary layers, in evolving aeroplanes which worm their way through the air rather than bullocking their way along as did the earlier bird cages; that we had learned to coax our way through the air; and that Professor Schlichting was one of the chief coaxers.

These pleasing thoughts were dispelled, just before the lecture, when I discovered that the Professor had come over by boat, all aircraft having been grounded by fog. I suppose the moral of this is that we ought to get a move on with our automatic blind landing schemes.

The aerodynamic fraternity is closely knit. Its activities permeate the whole aeronautical scene. Professor Schlichting graces this scene. He became well known in the thirties, during his association with Prandtl at Göttingen—that forcing ground of so many of the fundamental aerodynamic concepts which nowadays are taken for granted. Lanchester and Prandtl wielded hammers which beat out and forged the structure of aerodynamic understanding. In our lecturer, Prandtl found an apt pupil.

Professor Schlichting's early work at Göttingen on aerofoil drag in two dimensions is still remembered. At a tender age, after a spell in Industry, he found himself a Professor at Brunswick, and as Director he has stamped his personality on the Institute of Fluid Mechanics there. During his work at Brunswick he has come to epitomise the high academic tradition of choosing with insight and intuition programmes of highly relevant experimental work—often with relatively small scale apparatus—giving results which subsequently stimulate the mathematicians and illumine the body of knowledge built up with more elaborate facilities. Not only the aeroplane world has gained from his contributions to the understanding of boundary layer effects on swept and slender shapes, the influence of compressibility, and the fundamentals of transition and its control over the whole C_L range. The engine designers have also had cause to be grateful for his work on cascades and on the bases of turbine and compressor design.

In recent years, in addition to his duties at Brunswick, he has also been made responsible as Director for the Aerodynamic Testing Establishment at Göttingen; it must be giving him great satisfaction to build on such time hallowed foundations at Göttingen, in a laboratory which holds so many personal associations for him. To many of us it has been quite obvious that Professor Schlichting is one of the mainsprings behind the resurgence of the aerodynamic art in Germany. All of us who have listened to his lecture this evening must realise that his country has a great contribution to make in this field; a field in which her scientists played their full part during the early pioneering days.

I have much pleasure, on your behalf, in thanking Professor Schlichting for this memorable lecture. May I ask you to express your appreciation in the accustomed way.

Following the lecture a Dinner was held at 4 Hamilton Place, at which the following guests were present:—

Dr. A. M. Ballantyne, T.D. B.Sc., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S., Secretary, Royal Aeronautical Society. Professor A. D. Baxter, M.Eng., F.R.Ae.S., M.I.Mech.E., Director, de Havilland Engine Co. Ltd.; Member of Council, Royal Aeronautical Society. Mr. E. C. Bowyer, C.B.E., Director, Society of British Aircraft Constructors Ltd. Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S., Honorary Treasurer and Member of Council, Royal Aeronautical Society. Sir Aubrey Burke, O.B.E., President, Society of British Aircraft Constructors Ltd.

Sir Sydney Camm, C.B.E., F.R.Ae.S., Director, Hawker Siddeley Aviation Ltd.; Past-President and Member of Council of the Royal Aeronautical Society. Dr. W. Cawood, C.B., C.B.E., B.Sc., F.R.Ae.S., Deputy Controller of Aircraft, Research and Development, Ministry of Aviation; Member of Council, Royal Aeronautical Society. Professor A. R. Collar, M.A., D.Sc., F.R.Ae.S., F.I.A.S., Professor of Aeronautical Engineer-

ing, University of Bristol; Vice-President of the Royal Aeronautical Society. Mr. J. R. Cownie, B.Sc.(Eng.), Member of Council, Royal Aeronautical Society.

Sir William Farren, C.B., M.B.E., M.A., D.Sc., F.R.S. Hon.F.R.Ae.S., M.I.Mech.E., Hon.F.I.A.S., Technical Director of A. V. Roe Ltd.; Past-President and Member of Council of the Royal Aeronautical Society. Mr. L. G. Frise, B.Sc., F.R.Ae.S., A.F.I.A.S., Director of Special Projects, Blackburn & General Aircraft Ltd.; Member of Council, Royal Aeronautical Society.

Mr. R. W. G. Gandy, M.A., B.Sc., A.F.R.Ae.S., Secretary, Aeronautical Research Council. Sir George Gardner, K.B.E., C.B., D.Sc., F.R.Ae.S., M.I.Mech.E., Controller of Aircraft, Ministry of Aviation; Member of Council, Royal Aeronautical Society.

Mr. E. T. Jones, C.B., O.B.E., M.Eng., F.R.Ae.S., Deputy Controller, Overseas Affairs, Ministry of Aviation; Past-President and Member of Council, Royal Aeronautical Society. Air Marshal Sir Owen Jones, K.B.E., C.B., A.F.C., B.A., D.I.C., F.R.Ae.S., M.I.Mech.E., Vice-President of the Royal Aeronautical Society. Dr. W. P. Jones, M.A., F.R.Ae.S., F.I.A.S., Superintendent, Aerodynamics Division, National Physical Laboratory.

Mr. D. Keith-Lucas, M.A., F.R.Ae.S., M.I.Mech.E., Technical Director, Short Bros. and Harland Ltd.; Member of Council, Royal Aeronautical Society. Dr. P. W. Kingsford, B.Sc., Hatfield Technical College.

Dr. G. V. Lachmann, D.Ing., F.R.Ae.S., Research Director, Handley Page Ltd. Mr. George H. Lanchester, Brother of the late Mr. F. W. Lanchester.

Professor W. A. Mair, M.A., F.R.Ae.S., A.F.I.A.S., Francis Mond Professor of Aeronautical Engineering, Cambridge University. Mr. P. G. Masefield, M.A., F.R.Ae.S., Hon.F.I.A.S., M.Inst.T., Managing Director, Bristol Aircraft Ltd.; President, Royal Aeronautical Society. Mr. M. B. Morgan, C.B., M.A., F.R.Ae.S., Scientific Adviser, Air Ministry; Member of Council, Royal Aeronautical Society. Professor A. J. Murphy, M.Sc., F.I.M., F.R.Ae.S., Principal, College of Aeronautics, Cranfield.

Colonel R. L. Preston, C.B.E., A.F.R.Ae.S., Honorary Secretary-General, Royal Aero Club. Captain J. L. Pritchard, C.B.E., Hon.F.R.Ae.S., Hon.F.I.A.S., Secretary, Royal Aeronautical Society, 1925-51. Sir Alfred G. Pugsley, O.B.E., D.Sc., F.R.S., F.R.Ae.S., M.I.C.E., M.I.Struct.E., Professor of Civil Engineering, Bristol University.

Professor S. C. Redshaw, D.Sc., Ph.D., F.R.Ae.S., M.Inst.C.E., Professor of Civil Engineering, University of Birmingham. Professor E. J. Richards, M.A., B.Sc., F.R.Ae.S., Professor of Aeronautical Engineering, University of Southampton.

Professor Dr. H. Schlichting, The Lecturer; Professor of Fluid Mechanics at the Technical University of Braunschweig and Director of the Aerodynamische Versuchsanstalt, Göttingen. Professor A. V. Stephens, M.A., F.R.Ae.S., Professor of Aeronautical Engineering, Queen's University, Belfast.

Professor A. D. Young, M.A., F.R.Ae.S., A.F.I.A.S., Professor of Aeronautical Engineering, Queen Mary College, London University.

The Landing Gear of the SC.1 Aircraft

by

H. G. CONWAY, M.A., F.R.Ae.S., M.I.Mech.E.

(Director and Chief Engineer, Short Brothers and Harland Ltd., Belfast)

Introduction

The Short SC.1 is a small delta wing V.T.O. aircraft of about 7,800 lb. all-up weight. Its unusual feature is that it is provided with vertical thrusting engines to enable it to take-off and land vertically and to hover. It can also operate normally as a conventional aircraft.

The nature of the aircraft introduces a number of problems in the design of the landing gear. The first of these is that all wheels must be fully castoring since a vertical landing may take place with a certain amount of drift in any direction. Another complication arises because of the possibility of landing with slight backward drift, it being necessary to move the main wheels aft when the pilot intends to make a vertical landing; if the wheels were left in the required rearward position for conventional take-off the elevator power would be inadequate to lift the nose of the aircraft. The landing gear is therefore provided with simple means for moving the wheels fore and aft by a small amount, to move the position of the main wheels in relation to the centre of gravity.

Another unusual feature is in the comparatively high landing velocity which the specification calls for, due to the nature of the aircraft.

General Layout of Landing Gear

MAIN GEAR

The main undercarriage is illustrated in Fig. 1; the leg consists of a light alloy forging attached to the aircraft wing by means of a single pin. Drag bracing is by means of a hydraulic jack which also allows the undercarriage to take up either of two positions; forward for normal flight, rearwards for vertical landing. The sliding tube of the undercarriage carries a pair of wheels which are coupled together in rotation and arranged to castor freely. A pair of toggles connected to the axle housing is also connected to a rotating sleeve at the bottom end of the main light alloy forging. A castor lock is fitted here and is coupled in to the hydraulic circuit operating the main motion of the leg so that the castor lock is undone when a vertical take-off or landing is to be made (*i.e.* the leg is in the rearward position). The lock, however, is engaged automatically when the leg is hinged to its forward position, so that the castoring feature is not present when normal flight is taking place, and thus presents no additional problem to the pilot.

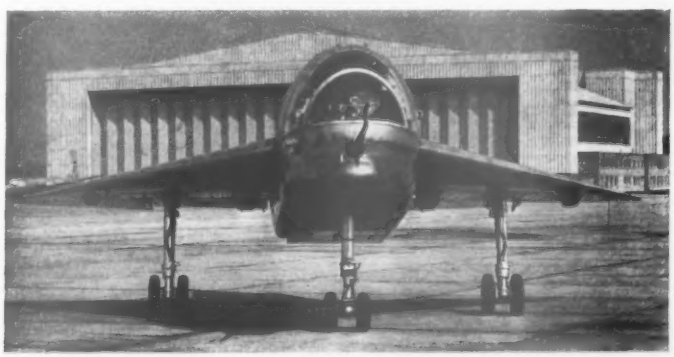
There is no danger to the pilot should he forget to move the wheels backwards when making a vertical landing. There is only a small risk that the aircraft might swing over or be blown over backwards onto the tail.

A self-centring cam mechanism inside the leg centres the wheels over $\pm 180°$ so that even if a drift landing is made under hovering conditions with a backward component of motion the wheels will centre again as soon as the aircraft takes off again or taxies forwards. Each main leg is fitted with a pair of wheels and tyres coupled in rotation to eliminate shimmy.

NOSE GEAR

The nose undercarriage is illustrated in Fig. 2. The leg consists of a main light alloy forging which is journalled to the airframe fuselage at a bearing some inches from the top of the leg and located by a pair of lugs and a pin at the upper attachment. These lugs deal with vertical and torsion loads. The leg is inclined forwards at some 13° and carries a pair of twin co-rotating castoring wheels.

An unusual feature of this nose landing gear is that the pair of wheels is also provided with a limited degree of rotation about a forward axis. This unconventional degree of freedom has been added because the aircraft may make drift landings in virtually any direction with rather more wing inclination than would be expected



The Short SC.1

Received 23rd November 1959.

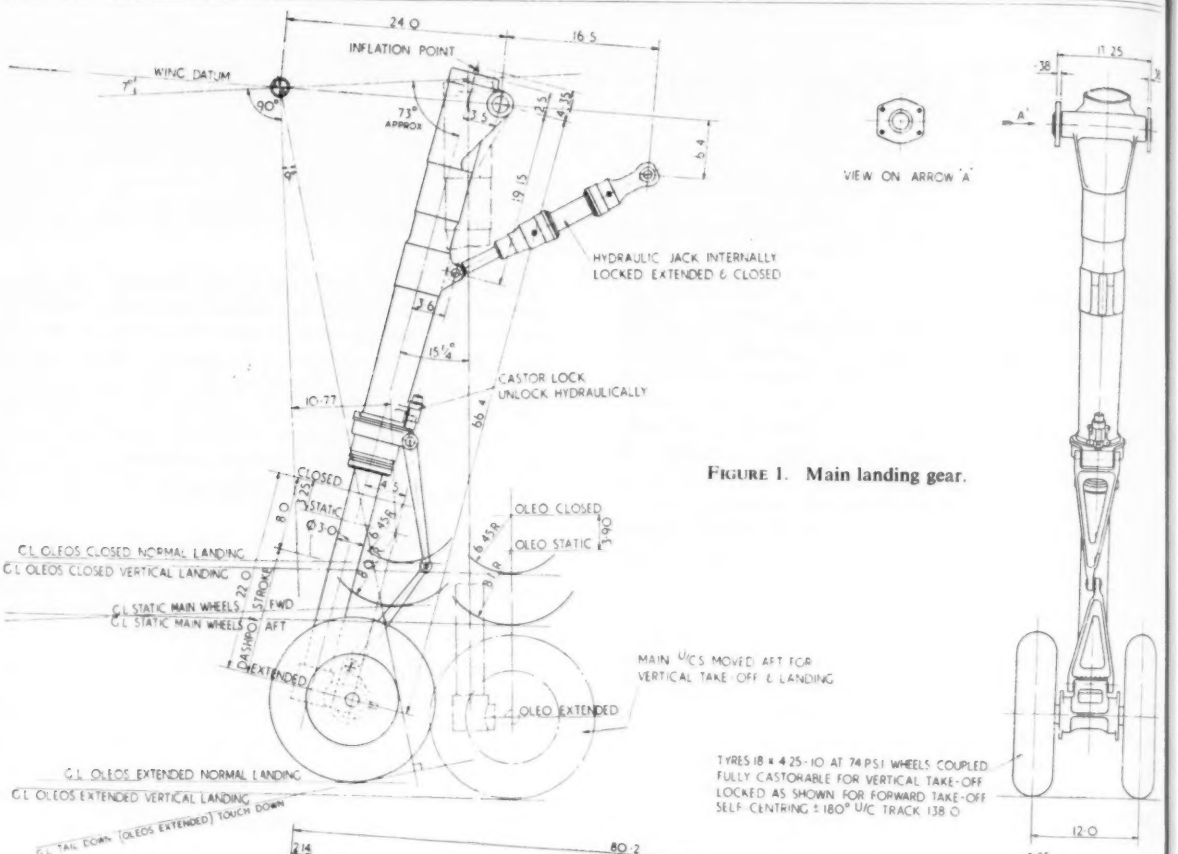


FIGURE 1. Main landing gear.

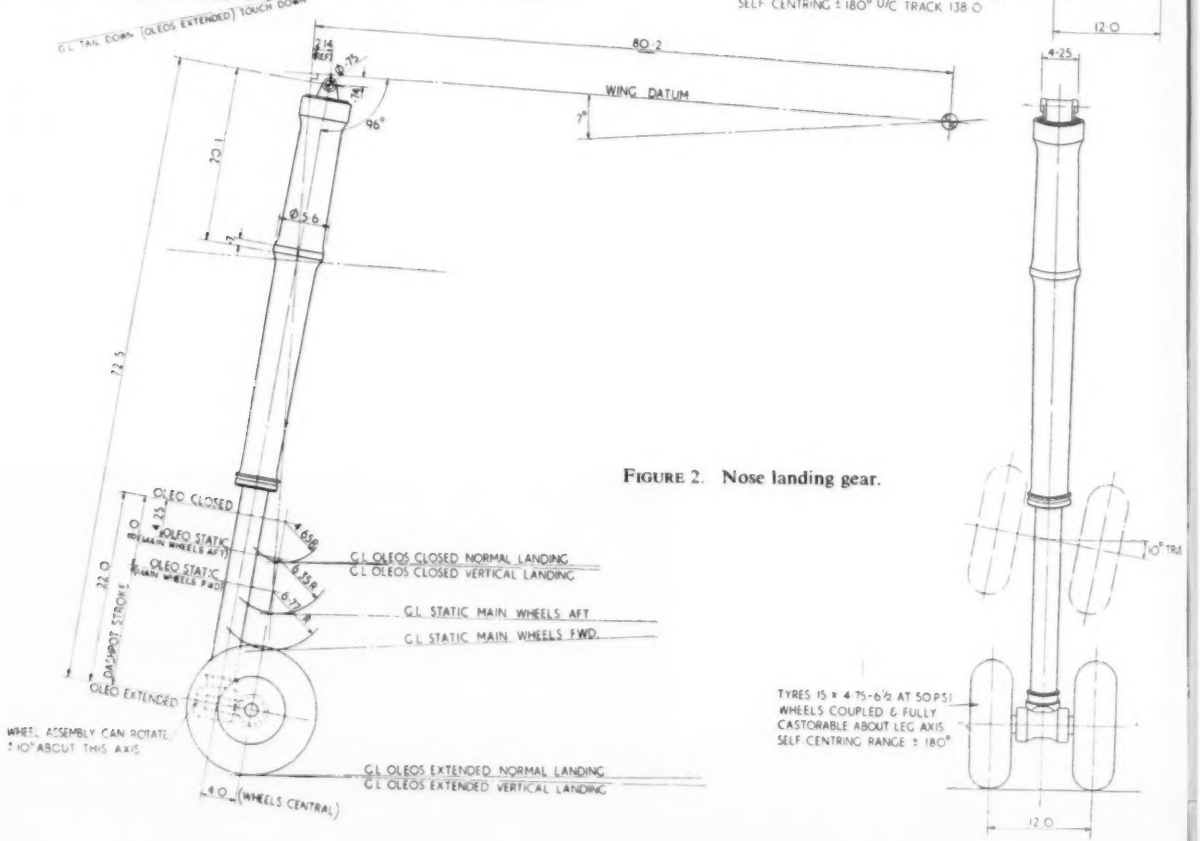


FIGURE 2. Nose landing gear.

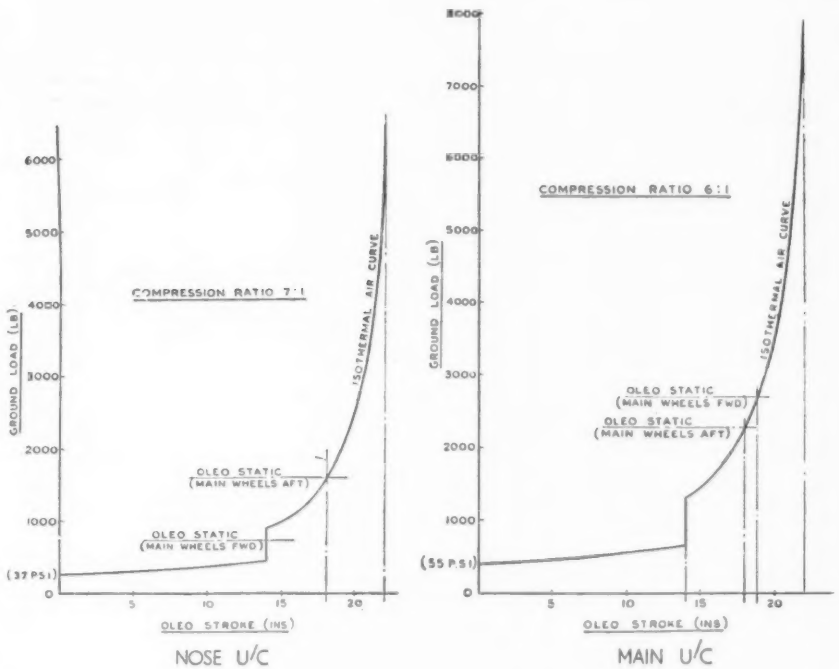


FIGURE 3. Shock absorber load/stroke curves.

from a normal aircraft. By providing this extra motion about a horizontal axis the two wheels can be kept in contact with the ground under all landing conditions, even when a hovering landing is made with one wing tip down and considerable drift. Experience has indicated that this feature is not in fact necessary.

The nose leg has a pair of wheels and tyres, coupled in rotation to eliminate shimmy. No brakes are fitted.

Shock Absorber Performance Requirements

Leg friction complicates the design of a long travel undercarriage system for a vertical take-off aircraft of this type. As the aircraft tends to take-off under vertical thrust, the aircraft will incline in one or other direction if the legs do not extend more or less evenly. A component of thrust in a horizontal direction is therefore set up and the aircraft will tend to move sideways along the ground. The legs must also extend freely during take-off so that they are immediately available for a landing should trouble occur with the take-off process. The present design has been devised with these points in mind and has proved completely successful.

The shock absorbing system has been further complicated by the requirement that the aircraft shall be designed to land, on the one hand as a normal aircraft at 12 ft./sec., and on the other hand under "helicopter" conditions at a velocity of 18 ft./sec.

The landing gear on the SC.1 meets the required specification by using a long travel shock absorbing system, the first 14 in. of the shock absorber travel closing a hydraulic dashpot, the last 8 in. operating a more normal oleo-pneumatic arrangement.

Curves of ground load against oleo stroke for the main and nose gears are shown in Fig. 3. The initial 14 in. of travel in either case compresses a small air volume with an extremely low compression ratio—the pressure being just sufficient to overcome friction effects. When the oleo reaches 14 in. stroke an additional piston comes into play and the normal polytropic compression takes place. The operation of the shock absorber is described in the next Section.

The drop test requirements for the two legs are as follows:—

MAIN UNDERCARRIAGE: (*a*) *normal type landing*
drop velocity 12 ft./sec.
acceleration factor 2·5
(*b*) *emergency "hovering" landing*
airborne drop velocity 18 ft./sec.
non-airborne drop velocity 13·8 ft./sec.
acceleration factor 3·25

NOSE UNDERCARRIAGE: (*a*) *normal type landing*
drop velocity 12 ft./sec.
(*b*) *emergency "hovering" landing*
airborne drop velocity 18 ft./sec.
non-airborne drop velocity 13·8 ft./sec.

Operation of Shock Absorber

The principle of the main shock absorber can be studied from the diagram in Fig. 4. The housing of

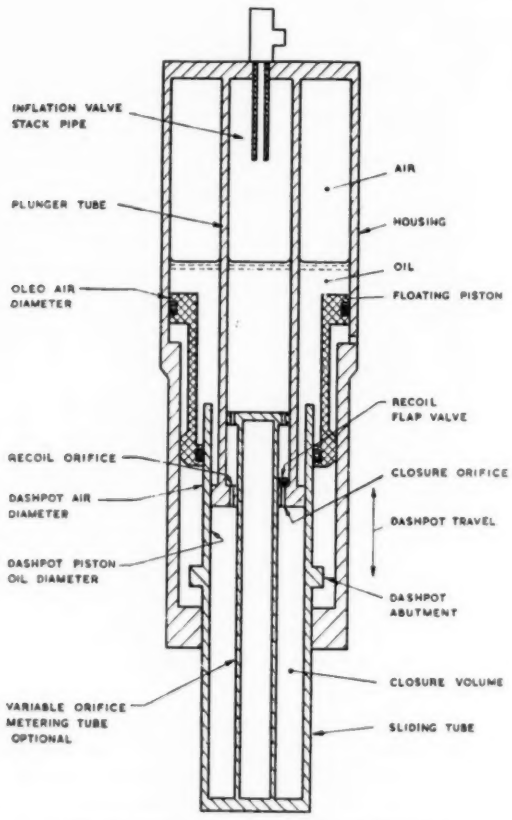


FIGURE 4. Diagram of main shock absorber.

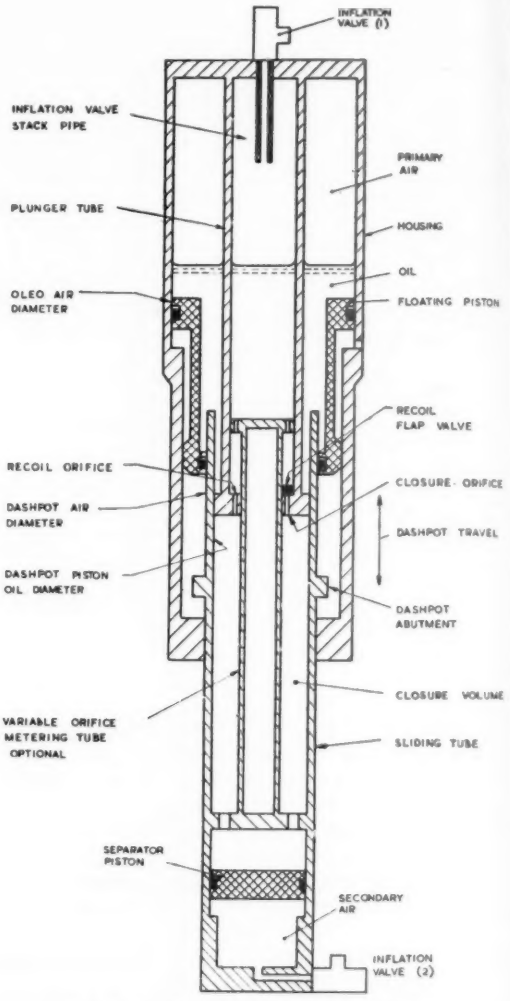


FIGURE 5. Diagram of nose shock absorber.

the shock absorber contains a floating annular piston. The sliding tube moves on a bush at the bottom of the shock absorber housing and on the inner diameter of the floating piston. Seals are fitted at this point and at the upper, outer diameter of the floating piston. Inside the sliding tube is a plunger tube with piston head, fixed to the top end of the housing.

During the compression stroke, oil inside the sliding tube is forced up through orifices in the plunger tube piston and compresses the air in the upper chamber of the shock absorber. An abutment on the sliding tube contacts the floating piston after the dashpot travel has been used up. The motion thereafter is that of the sliding tube and floating piston combined. It will be seen that the initial compression takes place on the diameter of the upper end of the sliding tube and that when the tube abutment contacts the floating piston the oil displacement is due to the full diameter of the latter piston. There is thus only slight compression of the air volume during the initial part of the travel (under dashpot action), and substantial compression over the latter part of the travel when the floating piston moves. The relative diameters of the inner and outer diameters of the floating piston are so arranged to obtain the required stepped compression curves illustrated in Fig. 3.

An additional central tube of small diameter is carried inside the sliding tube and passes through the main piston head. This enables additional area of orifice to be brought into play during the closure of the shock absorber to obtain the required oleo characteristics. Suitable holes in the tube provide this orifice area.

During recoil a flap valve on the piston head closes part of the orifices and restricts the extension of the leg. In the actual leg designs used on the aircraft there is no provision for positive recoil control as this is considered to be unnecessary. It is possible however on this design of shock absorber to fit positive recoil by adding appropriate orifices on the supporting head member at the upper end of the orifice metering tube.

On the nose shock absorber there is an additional air chamber with separator piston in the lower portion of the sliding tube, which has a high inflation pressure and a low compression ratio and is brought into play to reduce the maximum dynamic reactions during the early part of the dashpot travel, and to increase the overall efficiency of the shock absorber, when landing under "emergency hovering" conditions (*i.e.* above 12

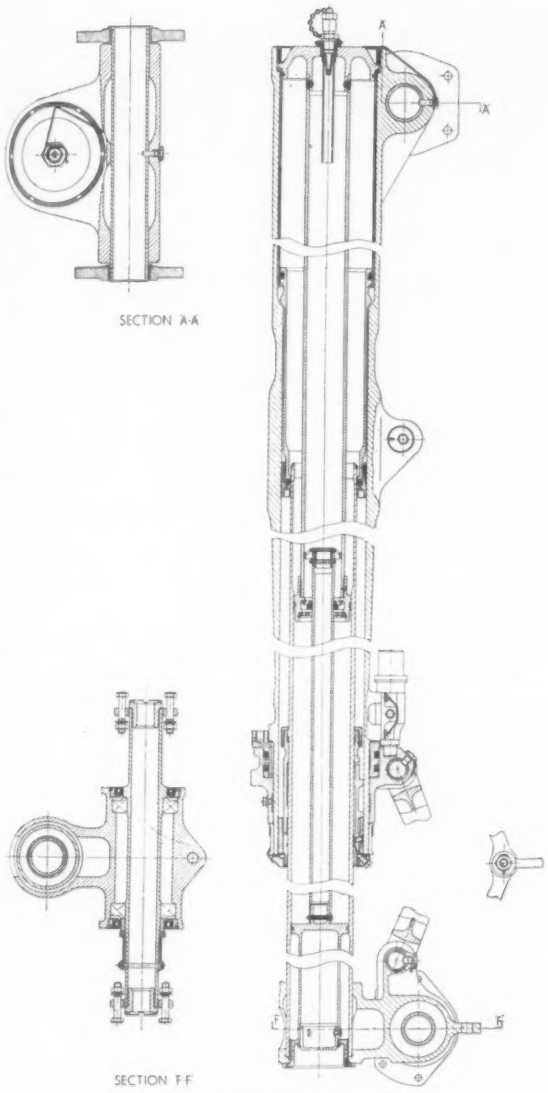


FIGURE 6. Main landing gear leg.

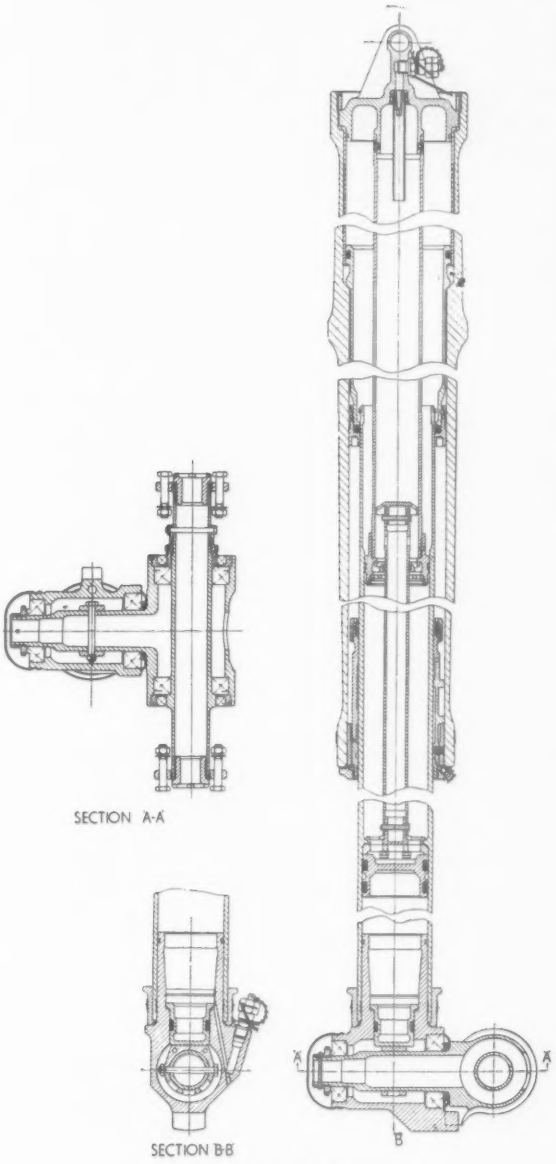


FIGURE 7. Nose landing gear leg.

ft./sec.). The principle of operation can be seen in Fig. 5, the unit in most respects being similar to the main unit.

Description of Main Landing Gear

Each main leg (Fig. 6) consists of a high tensile light alloy (L.65) forging, machined all over, in which operates the sliding assembly. The upper attachment is by means of a tube which is a sliding fit in the upper forging and retained in place by a hexagon-headed peg. A thin steel sleeve is inserted into the upper end of the forging and acts as a bearing cylinder for the floating piston. The latter has a pair of seals on its inner and outer diameters and carries a bush nut in its lower end; this allows the sliding tube to slide between the tube and floating piston over the dashpot part of the travel, and then the piston itself to slide in the housing over the last part of the motion.

The sliding tube bears at its lower end on a bush which is retained into the outer housing by means of a nut. The upper end of the bush is cut in the form of a cam and engages in another cam member attached to the sliding tube, so that oleo pressure centres the unit when the leg extends. Inside the sliding tube at the lower end is carried the orifice metering tube, and attached to the main housing and operating inside the upper end of the sliding tube is the main plunger assembly. The piston head on this assembly carries an orifice plate or flap valve to give the required closure and recoil orifice variations. The inner and outer

diameters of the plunger piston head are sealed to their respective tubes by means of split bronze piston rings.

The axle bracket assembly is clamped to the lower end of the sliding tube and carries a pair of taper roller bearings, in which the wheel axle rotates. End dogs between the wheel hubs and axle ends enable each wheel to be fixed rigidly to the axle to couple the two wheels in rotation, for shimmy prevention. A pair of toggle links connects the axle bracket to a rotating sleeve assembly at the bottom end of the main leg forging. A spring-operated, pressure-disengaged, lock assembly is bolted to the bottom end of the main forging and engages in the rotating sleeve connected to the upper toggle. When pressure is released from the small lock jack, a spring operates the lock pin.

The problem of supplying pressure (in this case pneumatic) to the wheel brake on a fully castoring undercarriage has been got over by a rotating seal assembly inside the sleeve. This assembly is normally free to move over $\pm 90°$ and does not rotate on the seals, provided the castoring of the two wheels does not exceed this angle. When a greater angle is required, the inner member of the seal assembly strikes an abutment and the seals then prevent loss of air while the joint is rotating. Since relatively few landings will be made with swivelling of more than 90°, the use of this device means that the seals in question are rarely disturbed and will thus have maximum reliability.

Pressure for emergency braking is supplied by means of a separate supply pipe running down the leg which, as in the case of the normal brakes, will rotate through $\pm 90°$ by means of flexible pipes. Should the landing be made with castoring more than 90° a weak link has been provided which will break the emergency pipe, thus allowing the wheels to castor freely. The pneumatic brakes have been chosen because of the risk of fire should a hydraulic leak occur at this rotating assembly or during an emergency landing.

The retraction jack is of conventional design, incorporating an internal lock with indicators operated by the lock mechanism. As already mentioned, this jack acts as a drag bracing member and enables the landing gear to be hinged into the forward or rearward position for landing under the normal or "hovering" case respectively.

Description of Nose Landing Gear

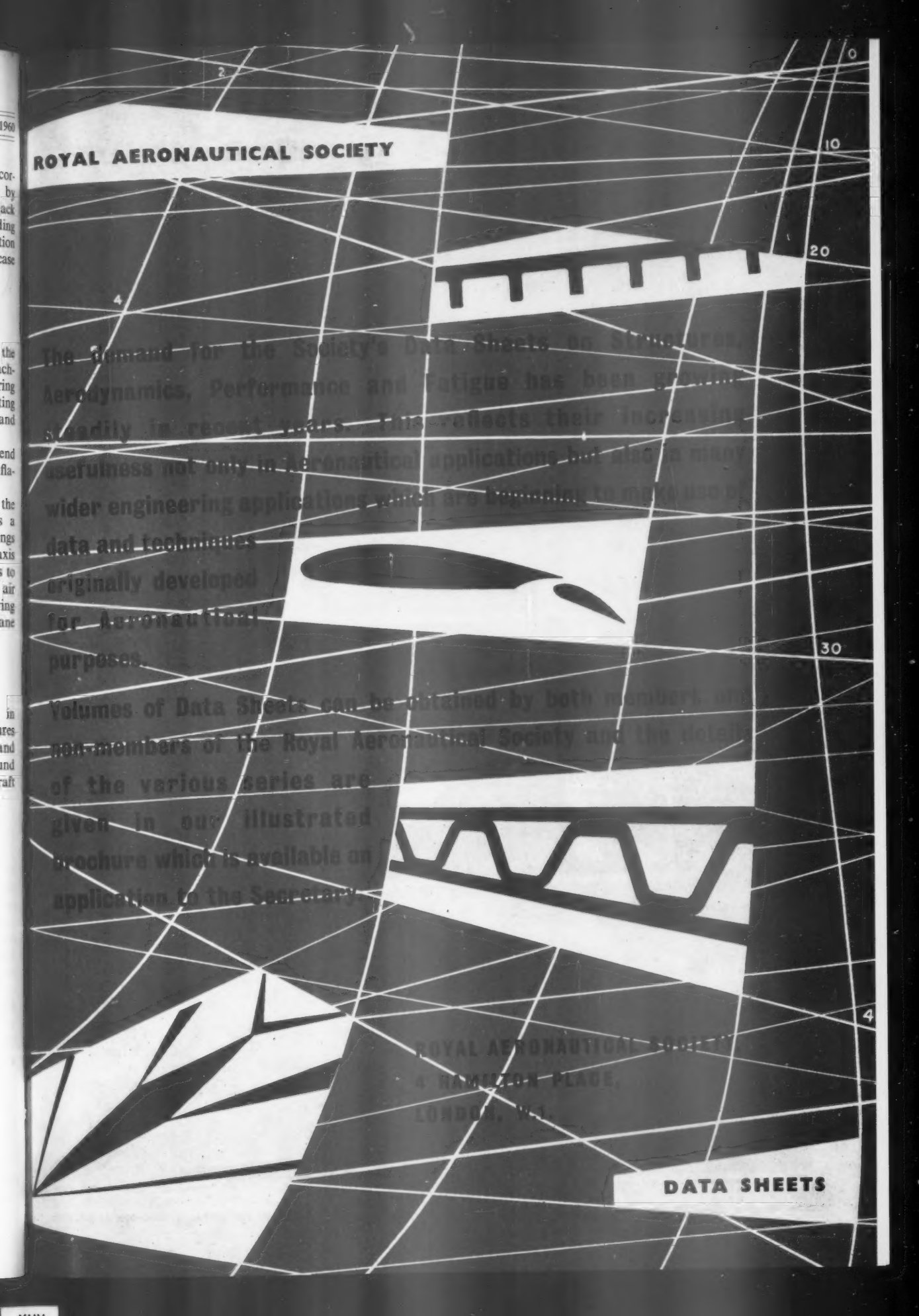
The nose landing gear (Fig. 7) is very similar to the main leg previously described. The method of attachment to the aircraft consists of a journal bearing towards the top of the main forging and a fork fitting with pin at the upper end dealing with vertical and torsion loads.

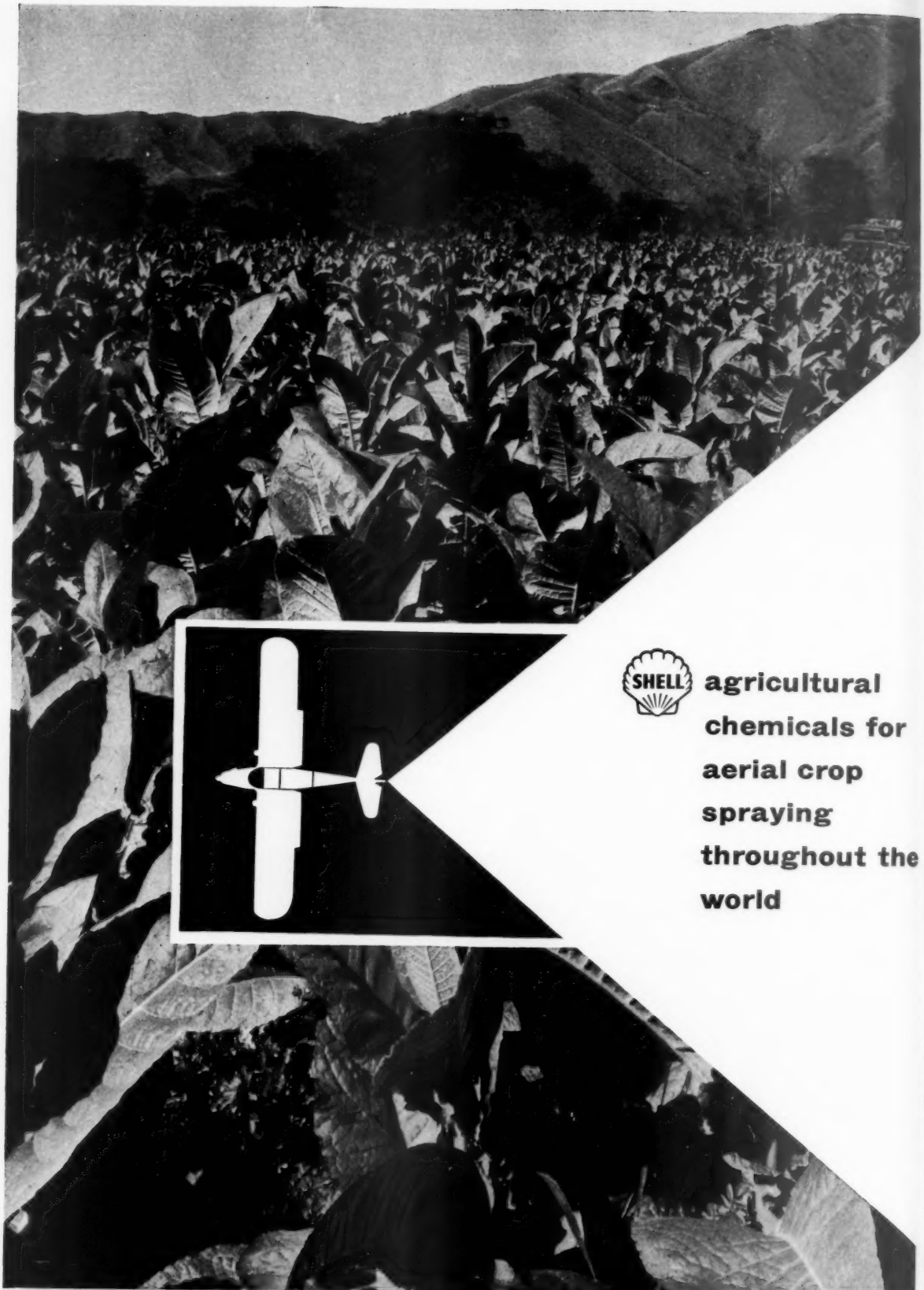
The additional air chamber is inside the lower end of the sliding tube which in inflated through the inflation valve placed on the axle housing.

The lower swivel bracket on the bottom end of the leg carries a pair of bearings, in which rotates a T-shaped swivel housing. The second pair of bearings in which the axle rotates is carried in the transverse axis of the T. The wheels are bolted and keyed by dogs to the axle, as for the main leg. A piston utilising the air pressure in the lower air chamber is used as a centring device which centres the wheels in the vertical plane when the aircraft is airborne.

Conclusion

This equipment, designed and manufactured in Belfast especially for the SC.1 incorporates features considered essential on all future V.T.O. aircraft, and has established that others which might have been found necessary are not required. Flight trials on two aircraft have been most successful.


ROYAL AERONAUTICAL SOCIETY
DATA SHEETS



Tobacco in Venezuela after aerial spraying with endrin • *Issued by Shell International Chemical Company Limited. For further information apply to your Shell Company.*

Agricultural Aviation

by

Air Commodore A. H. WHEELER, C.B.E., M.A.(Cantab.), F.R.Ae.S.

Development of Agricultural Aviation

The first International Agricultural Aviation Conference, held at the College of Aeronautics at Cranfield between the 15th and 18th of September 1959, was well timed to mark one stage in the development of the art of airborne farming—it was the stage when the art ceased to be mainly experimental and became essentially a commercial business.

Intermittently for the past thirty years, in various parts of the world, attempts have been made with varying degrees of economic and practical success to do certain operations connected with farming, forestry or other allied activities. Two main factors within the past decade have served to intensify the interest and activity in the art. One important factor is the general improvement in aircraft, including helicopters, coupled with the very large number of relatively suitable ones which became redundant (and therefore cheap) at the end of the Second World War. The other factor, equal in importance, concerns the development of the science of agricultural chemistry which has given the farmer a new and wide range of fertilisers, selective weed killers and other chemical forms of pest control which are effective in reasonably small bulk.

This recent increased interest in agricultural chemistry was largely forced on the farmers when they tried to obtain the high productivity per acre which they now achieve. The concentrated and specialised cropping, which is the agricultural analogy to mass production, gave all pests and diseases a much better chance of indulging their harmful propensities over the countryside where field after field offered them just the same suitable herbiage on which they could feed and breed. Apart from this factor some of the newer, highly bred strains of plants which have been developed tend to be less resistant to various infections than their more unsophisticated, almost indigenous, but less productive ancestors.

Had it not been for all the chemical and botanical developments which had a bearing on the situation and tended to tip the balance economically, there seems to be no good reason why aerial farming, on a reasonable scale, should not have developed after the First World War when cheap and fairly suitable aeroplanes were available from wartime stocks and all the basic principles of artificial fertilising were well known. In those days, however, it would have been quite a job to persuade a farmer to do his sowing and fertilising by using an aeroplane when many of them had not even started using a tractor. There are indeed still some who issue Cassandra-like prophecies about upsetting the balance of nature, but the human race has been doing this ever since it first sowed crops and weeded them or even made a clearance in a jungle. Nature also has been upsetting her own balance for millions of years and thus rendering extinct one species after another.

It may be said, therefore, that it is the general scientific development in agriculture, in the more advanced countries of the world, which has intensified the need for aerial assistance, and the scientific development in aviation which has made that assistance economically possible.

The Conference at Cranfield served to disseminate all the available information on the subject to those countries in Europe where agriculture has become an intense and scientific business. The information came from all over the world and although some of it may not have been of direct interest to farmers in Europe, all of the information was of direct interest to the aerial operators who need to spread their area of operations as widely as they possibly can to avoid off-season inactivity and thus to increase the utilisation of their equipment.

The Art of Agricultural Aviation in Basic Terms

In one sentence, and in its simplest possible form, one can say that the Art of Agricultural Aviation lies in getting the right substance at the right time on to the right place as cheaply as possible. The allocation of responsibility for achieving this, as between the various trades and professions, will be described in detail later but it is illustrated graphically in Fig. 1 wherein the inter-relation of the various responsibilities is well emphasised.

The Right Substance

In deciding what substance is to be used for any particular form of fertilisation or pest control—leaving aside for the moment rather specialised forms of aerial delivery such as seed sowing—the individuals to be consulted are botanists, biologists and chemists. Between them they will be able to say which fertiliser is needed or which chemicals will prove effective against the pest and unharmful to the crop. This selection must then be approved by the aerial operators who are advised by aircraft engineers, metallurgists and component manufacturers generally to ensure that the chosen chemical will not harm the aircraft structure or the spraying gear by corroding it, abrading it or dissolving it. They will also take advice from the doctors to ensure that the stuff is not unduly toxic to the personnel who handle it and fly the aircraft. Many chemicals

Received January 1960.

IN ORDER TO DELIVER THE.....	YOU WILL NEED THE.....							
	BOTANIST	BIOLOGIST	CHEMIST	METALLURGIST	DOCTOR	METEOROLOGIST	AIRCRAFT OPERATOR OR ENGINEER	MERCHANT OR CONTRACT AGENT
.....RIGHT SUBSTANCE	✓	✓	✓	✓	✓		✓	
.....AT THE RIGHT PLACE						✓	✓	✓
.....AT THE RIGHT TIME	✓	✓				✓	✓	✓

FIGURE 1. Specialist knowledge required for an aerial operation.

used today are corrosive, abrasive or toxic: some have two of these undesirable qualities, some all three. This does not rule them out for use but the operator will then need the advice of all his experts in deciding how to mitigate the harmful properties by such measures as diluting the mixture, painting and protecting his structure, washing down thoroughly after work, and providing his personnel with protective clothing. He must also bear in mind that some of the oils may dissolve the flexible connections in his engine and his spraying gear.

In all spray selection problems consideration must, to a certain extent, be given to other crops in the immediate vicinity since it is always possible that some drift of the spray will occur. A susceptible crop nearby may not rule out the spray but it is a warning that great care must be taken in applying it. Certain poisonous sprays must be applied an appreciable time before the harvesting of the crop to ensure that the poison will not still be on the leaves when the crop is eaten, and a further ramification of this point concerns a case where children were said to have eaten blackberries off a hedge which bordered a field which was sprayed with a toxic solution. Another point concerns wild life in the immediate area; they can be poisoned directly by eating berries or insects which have been contaminated; they can also be starved by the total destruction of the insect life on which they normally feed. Apart from humane considerations, much of this wild life may be a friend of the farmer by living on other pests, thus saving the farmer still further expense in pest control.

Preparation of the Substance

An important factor in providing the chemical substance for application is the form in which it is supplied. So far as sprays are concerned, droplet size is important and much more on this point will be said in dealing with the operators' responsibilities in delivering the spray on to the right area, but in this paragraph it can be said that, for effectiveness, sprays must cover the foliage as completely as possible to ensure that all infected areas are dealt with. For this purpose the smallest droplet size, *i.e.* the finest mist, is desirable although some assistance can be obtained if the spray is delivered when the leaves are already damp due to rain or early morning dew. Another method of improving the coverage is to use some forms of oil as a carrier diluent since certain oils tend to spread on the leaf, covering up to five times the area of a comparable water droplet.

Difficulty is experienced in getting the sprays on to the underside of the leaves where many pests live. A helicopter and, to a lesser extent, a very low flying fixed wing aircraft may tend to turn the leaves so that both surfaces receive some spray but this is rather a hit or miss arrangement. Some of the pests do come out from below the leaves and walk about on top, usually at night, and thus get poisoned but there are quite a number of what we might call permanently subfrondular pests who stay underneath. In default of better means of spraying, this type can best be dealt with by spraying the foliage with a solution which the leaves absorb and which thus renders them poisonous to the pests who suck their juices from below.

Other Substances for Aerial Delivery

Apart from the normal application of chemicals in dust, liquid or pellet form for the purposes just described, a certain amount of specialised work has been done in New Zealand which is somewhat surprisingly described as "aerial ploughing". This activity calls in most of the experts in their various lines of knowledge and amounts to clearing rough, unproductive terrain of weeds and scrub with a comprehensive plant killer. The area is then sown with a suitable crop, usually grasses with valuable feed properties, and fertilised with any trace elements which the soil may lack. If the old weeds show signs of returning the area can be sprayed again with a selective weed killer.

In places where this process has proved exceptionally successful the work has been taken a stage farther by dropping fencing materials from the air so that

animal feeding could be controlled and made even more efficient.

The Right Time

Only the botanist and the biologist are really needed to decide on the right time for the control of various pests, the destruction of various weeds, or the sowing of various seeds. This implies no reflection on the farmers' knowledge since it is assumed that the farmer knows a certain amount on all these subjects but needs to call in the specialists as the situation demands: indeed it is his requirements to which all the specialists are working.

So far as time is concerned the operator merely wants to know the earliest possible date at which he may start and the latest possible date by which he must have finished: between those two dates he does as much as he possibly can, as quickly as he possibly can, for all his customers.

The Right Place

The right substance and the right time are essentially a matter for long planning and considerable research since they are affected by the biological facts connected with diseases, the life cycle of insects, and the growing seasons of plants. Putting the substance down in the right place is almost exclusively the responsibility of the aircraft operator on advice by the agent (often a local seed merchant or agricultural contractor), and with day to day assistance by the meteorological officer who can tell him about possible wind conditions, low level turbulence, squalls, inversions and visibility. All of these affect his ability to put the substance down on the area intended.

Assuming weather conditions are satisfactory the operator must plan his work with care to ensure that all concerned know which fields are to be dealt with in which order, that the areas are adequately marked, and that surface borne supplies will be delivered correctly. Marking the areas not only means the presence of the "markers" who are positioned at each end of the flight swath and move on one swath width each run, but it may also involve making absolutely certain that the field itself is clearly indicated. Cases have been known frequently where either the wrong field was sprayed or one field was sprayed twice over; in either instance the customer is unlikely to pay for that part of the operation.

These errors are not so likely to occur when helicopters are used, operating from the same or an adjoining field, as when a fixed wing aircraft is operating from a base which, of necessity, may have to be four or five miles away.

Under this heading—The Right Place—we may include the important point of accurate distribution and density of the substance. Even with the most advanced designs in distribution gear there is a tendency for liquids, dusts, or pellets (forms in which substances are usually supplied) to distribute themselves on arrival at the surface with some degree of unevenness. This may be due to factors such as natural turbulence, turbulence induced by the aircraft, ordinary wind drift, and so on.

One way of adjusting minor irregularities of distribution and density is obviously to cover the area twice, possibly running at right angles on the second coverage, but this is almost prohibitively expensive and would still not take care of the larger errors due to wind drift. These irregularities can, at best, only be mitigated by trying to ensure that the particles, whether they be liquid or solid, drop quickly; to achieve this they must be large and solid to give them a small surface in relation to their mass. In the case of fertilisers this can be an advantage since a suitable size of pellet which will drop quickly will then dissolve slowly, thus extending the period of its effectiveness over a longer time. In almost all other cases where pest control (weed, virus or insect) is concerned the two requirements are irreconcilable. The solids must be in dust form with very small particles and the liquids must be delivered in as mist-like form as possible in order to smother the foliage.

For solids there has been a tendency to get away from forms of dust because of the difficulty of ensuring even distribution; with liquids, determination of droplet size has become of paramount importance.

Liquid Droplet Size

As mentioned previously, if a liquid is delivered in a form which is so fine that it is essentially a mist then, under many normal meteorological conditions, it may drift a considerable distance. A suitable size of droplet, from the biologist's point of view, would be between 5 and 50 microns but to ensure a sufficiently rapid descent from the aircraft the minimum size should be about 200 microns. For practical spraying and to avoid embarrassment with neighbouring farmers, the droplet size must be of the larger variety and various means must be found for making this size effective biologically.

Invert Emulsions

One promising method has been found in the development of what are called Invert Emulsions wherein the active agent is in oil which surrounds a water droplet. In this form there is little evaporation on the way down and the oil also spreads more effectively on the foliage. With water only, cases have been known when a droplet of critical size has dried slightly during descent, become smaller than the critical size, and then started to ascend and drift away. An additional advantage of invert emulsions is that they can be white in colour so that they mark their own swaths after each spray run.

The Operator's Technique and Tools

Enough has now been said on the chemical and biological side of the problem to indicate, in broad terms, what the operator has to do and all the pitfalls he must avoid in doing it. It has been shown that some of the requirements for good aerial delivery are irreconcilable with one another. Consideration can, therefore, now be given to the methods employed by

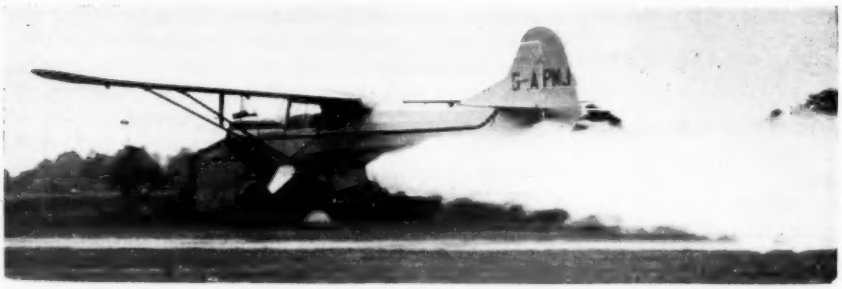


FIGURE 2. Dust distribution direct from hopper on an Auster Workmaster.

Courtesy of "The Farmer and Stock-Breeder"

operators and the equipment they use. It will be convenient to start with the aircraft which are, or might be, employed and then describe the spraying or spreading equipment which can be fitted to the aircraft.

The Aircraft

Since the essential technique of distribution involves flying to and fro in swaths across an area it follows that the aircraft used must be able to turn quickly and safely at the end of each run. Since it must usually operate very low, almost with its undercarriage in the crop's foliage to avoid drift, it must be very controllable even when fully loaded. It will also be required frequently to land and take-off from short strips and the take-offs will always be at full load. Within limits, the higher the load the more economical the operation so the aircraft must be able to withstand all the structural and aerodynamic hazards of repeatedly landing as short and expeditiously as possible and then taking off again at full load.

All these considerations would seem to point overwhelmingly in favour of the helicopter with its ability to land in the same field in which it is operating and with its inherent controllability at all speeds, but the high initial, and operating, costs of the helicopter leave the fixed-wing aircraft with a big share in the work. This is particularly so where large areas and heavy loads have to be dealt with. This is a condition which obtains in many parts of the world. An additional, but temporary, factor is the large number of redundant ex-war-stock fixed-wing aircraft which have been available at a price far below anything which would economically be charged for a new machine. As a result of these, and other, factors it is not possible to lay down any hard and fast operating limits for either fixed-wing aircraft or helicopters.

For fixed-wing aircraft a number of safety considerations needed attention beyond the obvious ones already mentioned, in connection with slow flying characteristics, good stalling properties with extremely effective stall warning, and short-run landings and take-offs. The hoppers need to be so positioned that they are not a danger to the pilot, either in normal flying conditions or in a crash. Opinion is divided on this since some authorities say that the hopper should be in front of the pilot for the crash case, others say that, if positioned in front, toxic materials or their fumes may get into the pilot's cockpit and poison him. It is also said that the hopper should not be close beside the pilot, so reconciliation of these viewpoints is difficult. Some helicopters have their hoppers situated on each side of the cockpit and outside it. A position in fixed-wing aircraft favoured by some designers is behind the pilot but below him, so that danger in a crash would be mitigated.

One way to reconcile all requirements might be to design a larger twin-engined aircraft with hoppers behind the engines, thus giving the pilot an uninterrupted view forward and ensuring that the chemicals which are ejected do not come in contact with any of the aircraft's structural parts. Such an aircraft, however, would need to have very good control characteristics to take care of engine failure or load discharge irregularities. If such a large aircraft were built, consideration should be given to range for ferrying from one operational area to another—including seasonal moves from one country to another as transportation by surface means would be expensive. This should not be a difficult problem since over-load tanks could either be placed in, or replace, hoppers. For the actual operational work, range or endurance is of little significance since the aircraft has to land every few minutes anyhow to replenish its hoppers.

Distribution Equipment

In the main there are two separate problems in distribution: there is the problem of even spreading of fertilisers which are now supplied in the form of dust or pellets, the latter usually being about the size of granulated sugar but might be larger, perhaps up to the size of peas. The other problem is spraying liquids which, although their fluid qualities allow of a normal pumping action for ejection, have some undesirable

Courtesy of "Flight"

FIGURE 3. Spray boom and gear on a Jackaroo.

qualities such as corroding or dissolving materials; some also carry abrasive particles and in that respect need special consideration so far as spray equipment is concerned. Many of the liquids also carry their active ingredients in suspension; these would tend to settle if the liquid is not stirred at frequent intervals. In the air this is easily done by by-passing the pump to agitate the tank fluid during the turns between runs. This also avoids the stresses which could be induced by suddenly halting a fluid flow.

Apart from these main problems there is a growing technique for seeding from the air. At present this is chiefly done in rugged country difficult of access by surface vehicles, but farmers even in this country are alive to the fact that, in some wet seasons when their cultivation is delayed, it might be better to pay the higher price to get the sowing done from the air—on time—than to get the seed in too late with the inevitable late harvest and low yield. The fact that seed thus distributed might be subject to depredation by birds can be taken care of by pre-treating the seed to make it unpalatable to them. On the whole seeds do not mind being merely dropped on the surface and not covered: in the natural state this is their normal treatment. At the present time, much development work is going on to investigate the possibility of encasing each seed in a standard sized pellet which could be ejected with a reasonably even distribution. The pellet covering would include the pre-treatment of the seed to render it immune to disease and unpalatable to birds; it could also include any required fertiliser to give it a good start in life after germination. This development, however, is more in the future than the present.

Distribution of Fertilisers in Solid Form

Although there are quite a number of problems involved in ejecting solid particles or dust the basic method is straightforward. The substance is loaded into a hopper, either by hand from bags or tipped from a tractor loader as in other agricultural activities; it is then allowed to fall out when a large shutter is opened in the bottom of the hopper. The required rate of discharge for most fertilisers is high, thus difficulty is experienced in getting an even distribution and the flight time for each operation is reduced. Since the substance for distribution is usually both corrosive and abrasive great care must be taken in cleaning down after each day's work.

Spraying

The technique of spraying can be divided into two distinct methods. The liquid spray can be ejected by a rotary atomiser or forced out under considerable pressure through a nozzle. In both cases the slipstream past the ejection point has a definite effect in breaking down the stream into droplets.

Rotary atomisers are usually wind-driven and for this reason could not be used easily on a helicopter, although a power-driven atomiser would be perfectly practical. With all rotary atomisers it is claimed that droplet size can be controlled within fine limits by

Courtesy of "Power Farming"

FIGURE 4. Djinn with spray boom operating: cylindrical spray tanks on side.

various permutations of gauze size (through which the spray is ejected), rotation speed of the atomiser and air speed over the ejection point. The atomisers can act as their own pump since their rotational speed is always high but this high r.p.m. carries its own dangers in the case of windmill blade failure. Consideration to this eventuality is always given, either by locating the atomiser so that broken parts will fly clear of the aircraft structure and pilot or, by providing a protective shield. Rotary atomisers are shown in Figs. 6 and 7.

The alternate method of spraying is by high pressure pump through a large number of nozzles located along a "spray bar." This is designed to be as long as practically, and aerodynamically, possible in order to give the widest possible swath. Practical difficulties which arise in designing this equipment concern the necessity to make it stiff enough to withstand aerodynamic and vibratory loads and still be light. For fixed-wing aircraft drag is an important point to watch since, even at the low flying speeds which are normal, the engine is working hard during turns. In the case of fixed-nozzle spraying, droplet size can be controlled by the size of the nozzle, the ejection pressure and the air speed past the orifice: because of the third factor it is usual to arrange for the spray to eject either into or across the air stream—downstream ejection would have little or no effect in breaking up the droplets.

As would be expected, delays occur through the need to change or clear blocked nozzles, which is a

Courtesy of "Western Morning News"

FIGURE 5. Helicopter Services' Bell spraying: conical hopper on side.

FIGURE 6. Rotary atomiser in operation.

Courtesy of "The Farmer's Weekly"

fairly frequent occurrence with some mixtures. Since it is important to have an immediate cut-off of the spray at the end of each run the nozzles are usually provided with a pressure release valve which only opens when the pressure from the delivery pump is turned on and which closes again immediately the pressure falls off, thus preventing dribbling during the turn—which might be over another crop. The pilot of the aircraft has an indication of blocked nozzles or pump failure by a pressure gauge in the cockpit: if the pressure is unduly high it is an indication of a blockage (usually at the nozzles); if the pressure is too low it is an indication of pump malfunctioning or failure along the pipe lines.

In all cases of engine-driven spray pumps it is a requirement that there shall be a weak drive link in the system so that heavy loads on the spray pump shall not be transferred to the engine accessory drives.

Harmful Effects of Some Substances

The most common harmful effect from chemicals delivered from the air is corrosion and probably the most common of the harmful chemicals are among the copper sulphates and copper oxychlorides. The list of chemicals used is too long and too complicated to give in this paper but all manufacturers are able to supply a list of their own products—some of which are given under trade names and are not thus an indication of their chemical composition.

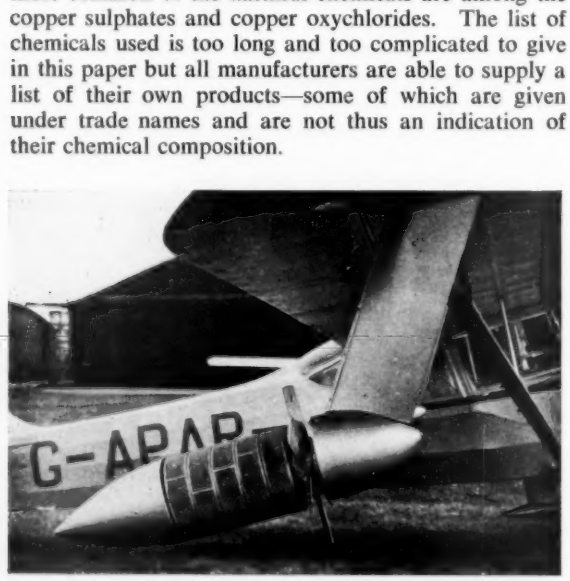


FIGURE 7. Rotary atomiser on an Auster.

In general it may be said that stainless steel will resist nearly all likely spray materials but is heavy and expensive; aluminium and some of its alloys will resist many although some of the light alloys can be seriously attacked; copper, bronze and that family of alloys are resistant but heavy; mild steel is strong, cheap and fairly resistant, particularly when covered with a protective coating of paint. All the above are unaffected by heat so far as their strength is concerned but all are affected, on the corrosion side, by the increase of heat. It must be remembered in this connection that temperatures up to 80°C can be encountered in some parts of the world if the aircraft or the chemical bowsers are left out in the mid-day sun.

This question of temperature, therefore, has an important bearing on the use of the various plastics, polythenes, fibreglasses, and so on, all of which start to lose their strength very rapidly with the high temperatures or high light intensity which might be encountered in equatorial regions of the world. Another consideration in non-metallic materials is the dissolving properties of some oils. Many are resistant to this but various oils are used as spray carriers and paraffin or its allied petroleum products are in constant use for insect control. All glands, pipe connections, and so on, must be proof against deterioration when they come in contact with such oils.

Some Other Activities in Agricultural Aviation

Agricultural work also includes many other activities, even though they are on a small scale by comparison with the distribution problem mentioned already. In some parts of the world, particularly in the cattle and sheep raising areas, the aircraft is used for locating and counting stock. In forest areas a considerable amount of fire watching is done in the dry season. In areas where vermin of one kind or another are a serious menace they can be spotted and sometimes attacked from the air. And apart from these diverse activities there are many farmers, living far from any town, who use an aeroplane regularly as a run-about.

Conclusion

It has only been possible to deal superficially with the very wide subject of Agricultural Aviation, which was covered in considerable detail during the Cranfield Conference, but it is hoped that enough has been said to indicate that Agricultural Aviation is an important and a growing business—one day it will be big business.

Aerial Operations Planning in the United Kingdom*

by

PETER J. W. KING, M.A.

(*Crop Culture (Aerial) Ltd.*)

Introduction

Sporadic commercial aerial spraying operations have been undertaken in the United Kingdom for more than a decade but only over the past two or three years has it been possible for companies to make a sustained attempt to plan their work in a way which will put operations on a self-supporting annual basis.

Today, the degree to which an operator will plan his work is largely a matter for him to decide; there are few legislated requirements. The law as it stands specifically permits the work of the agricultural operator and leaves him—in the main—to order his affairs as he thinks proper. However, it cannot be long before the incidence of accidents and public anxiety about the effects of drifting chemicals brings about a change in the official attitude towards the Industry. Looking ahead we must expect some form of licensing to be introduced, which will require all operators to meet a standard set by the Ministries of Aviation and Agriculture.

In few other areas of the world is agricultural work with aircraft so difficult as in the United Kingdom and our Industry presents a formidable challenge to the planner. Furthermore, the price structure which has prevailed up to the present time has been a depressed one—operators have been supplying too much for too little. Close study of the economics of agricultural work here proves that there is no way open to make a substantial reduction in costs. The price the operator charges, if he is to stay in business, must therefore go up. But, if he is to ask more for his services, the contractor must ensure, by careful planning, that he is offering the best possible value for money.

1. The Strategy of the Campaign

1.1. THE WORKING SEASON

The operator's first consideration in determining his overall planning policy will be the pattern of utilisation, which in turn follows from the work season which he believes he can reasonably predict. The extent of the season is a function of the contracts available, the period during which they are to be fulfilled and the weather limitations.

In general the work pattern divides itself into three or four main phases:

First is cereal fertilising beginning in January or February and slackening off in March and April with late top dressing following in May and June. In May, insecticidal work begins, continuing to June and sometimes into July and August. Finally there is fungicidal spraying against potato blight from late June until August.

Mention must also be made of a number of miscellaneous spraying jobs, including trace element applications and sprays on orchards and hops.

There is some optimism about the prospects for marginal land improvement with phosphate or lime, weed and bracken killing and the planner of the future will, it is hoped, also be able to include these in his spectrum. But as it stands today the United Kingdom season extends for a maximum of eight months, beginning in January and coming to an end during August.

1.2. UTILISATION OF AIRCRAFT

Alongside his estimates of the working season, the operator will set the pattern of optimum utilisation for his aircraft.

To assess utilisation accurately, it is necessary to make a realistic appraisal of the likely number of hours which will be flown during the season. So far as is known, no meteorological records exist which will give this information. Wind, bad visibility and poor weather generally, limit the number of "flyable" days per month more severely than is recognised. During the four months from February to May, experience shows that the flying time each "flyable day" will average between two and a half and three hours. But far from every day in this period is "flyable" for one or more of the following reasons:

(*a*) bad weather *en route* preventing the aircraft from arriving on the job.

(*b*) bad weather on the job.

(*c*) aircraft unserviceability.

(*d*) crew rest periods.

Taking these factors into account, the average flying time *per day* in the first half of the season may be as low as one and a half to two hours.

Over the last three months, that is from June to August inclusive, the average will increase to perhaps four hours per "flyable" day.

Taking the best representative averages, it is clear that utilisation cannot be expected to exceed about 400 hours a year.

In practice, utilisation will often fall below this level,

*The second lecture given before the Agricultural Aviation Group—on 11th December 1959.

largely because of periodic fluctuations of demand. This is illustrated in Fig. 1. Graph A shows month by month the acreage treated by a fleet of aircraft in the United Kingdom. Graph B shows the same fleet's flying hours. The variations are not nearly so marked in the second graph because fewer acres are treated per flying hour during the top dressing phase.

The utilisation achieved with a helicopter over the spraying season should be greater than that of the fixed-wing machine because it is relatively less susceptible to wind conditions. However, helicopters have yet to be developed for fertiliser application and their annual utilisation is low.

Allowance must also be made for unproductive "dead" flying time (that is flying not involved in the spraying operation itself) which will probably average 20 per cent of the total; but when contracts are scarce and the aircraft is flying from one district to another looking for work, landing strips, and so on, it may be as high as 30 per cent. Again the helicopter should show a relatively better performance.

1.3. HOURLY ACREAGE OUTPUT

The experience of the author's company suggests that a small light aircraft of the Tiger Moth or Auster type will achieve about 20 acres per hour fertilising and double this figure when spraying. A small helicopter such as the Djinn, Bell or Hiller will have a higher work output than the fixed-wing aircraft, achieving about 60 acres an hour (spraying only).

These figures are averages which may be exceeded under good conditions, but discussion with a number of operators suggests that they are frequently not attained. Higher than average application rates will of course reduce the work output in terms of acres/hour.

Taking these rates and the utilisation quoted earlier, the average acreage expectation per aircraft for each month of the season will be:

February	1,050
March	1,050
April	1,050
May	1,600
June	2,250
July	3,000
August	2,000

giving a total of 12,000 acres.

These monthly totals are not high and far higher figures are achievable on contracts which call for two or more applications on the same crop.

2. The Sales Planning Phase

2.1. INTRODUCTION

It is of the utmost importance that the sales force is given accurate information about the work targets for each month. The salesman can do far more than is perhaps apparent to find work for the aircraft. Equally important, he must not over-book the aircraft through ignorance or optimism about its real capacity. Farmers who book aircraft which fail to arrive on time may (quite rightly) be severe critics of the aerial contractor.

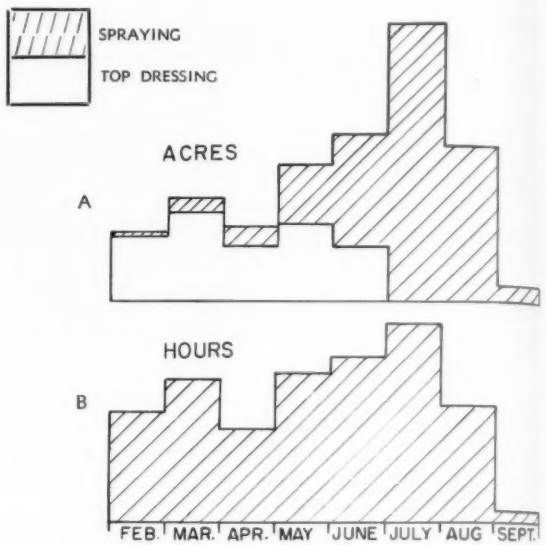


FIGURE 1.

The salesman for agricultural aircraft operations may be the operator himself or he may be a merchant or agent. Merchants can be a most powerful exponent of the advantages of aerial spraying and the Industry in this country owes much to those who have actively supported it over the initial period of growth.

There are many ways in which aerial spraying can be "merchandised." Demonstrations can be given, articles written in the merchant's catalogue and in the local press, together with advertising, evening lectures and film shows, canvassing at markets and on the farm itself. All these various sales media must be exploited.

The salesman's job is to sell to a plan and to provide as much work as the fleet can undertake over a full season. This work must be concentrated as far as possible in what has been aptly described as an "orbit."

Figure 2 illustrates the very substantial acreage which may be found within orbits of varying radii from a fixed point. As can be seen, in ideal circumstances

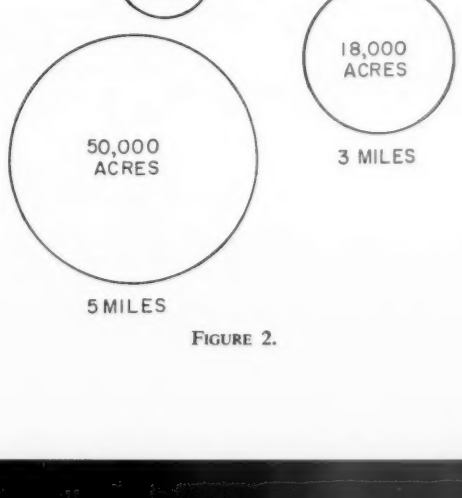


FIGURE 2.

a salesman can confine his efforts to a comparatively small geographical area.

2.2. CHOICE OF LANDING STRIPS

In many parts of the United Kingdom landing strips are not easy to find and it is therefore often desirable to build up the orbit round an existing air strip. Once having found a suitable landing field, it may be advantageous to pay the owner a small sum to preserve its use from one season to another. On no account should the selection of a landing strip be left to an inexperienced individual, and careful inspection is necessary before use.

With difficulty, it is sometimes possible to obtain permission to operate from disused military airfields owned by H.M. Government. However a lengthy period of notice of intention to use the field is usually required and a substantial charge is made for each take-off and landing. A more liberal Government policy towards use of these fields would be welcomed by the Industry.

2.3. SUITABILITY OF WORK AND AVOIDANCE OF HAZARDS

Those responsible for selling an aerial agricultural service must have a clear understanding of which types of field are suitable for treatment and which are not. Hazards in the form of high trees, power lines and other obstructions are not only dangerous but they reduce work output. The author's company distributes a leaflet (Fig. 3) which illustrates, for the benefit of the merchant's representative, the hazards which may be encountered.

The representative who sells aerial work must be aware of the public relations aspect of his job. He must, for example, avoid continuous noise near hospitals and operations near sensitive poultry or mink farms. He must also have knowledge of flying regulations which restrict low-level flying near populated areas. These regulations are far from easy to interpret and, although pilots have been prosecuted for contravening them, it is hard for the operator to give the uninitiated a clear policy here. Complaints will usually be avoided if neighbours are warned that aerial work is taking place in the vicinity. The local police should always be informed.

2.4. CYCLES OF SPRAYING

A further difficulty which presents itself to those planning the work programme at this stage is that of making allowance for the cycles of spraying which must be undertaken at regular intervals on many crops. The contractor is expected to provide prompt service on or about the date required by the customer, yet the broad timetable, laid down months in advance, may fail to indicate whether two, three or four cycles will be called for. We are told that they order these affairs better on the Continent; in Holland some six or eight sprays may be booked by the grower for the potato season. It would make the planner's task far easier if farmers could be encouraged to order a specific number of treatments each year as a prophylactic measure, but such an ideal is hard to envisage here.

2.5. SUMMARY OF SALES PLANNING

To summarise the various aspects of the planning task which are commonly the responsibility of the selling agent, these are:

(*i*) To create a demand for the aircraft sufficient to provide it with work over the season.
(*ii*) To ensure that this work falls within a concentrated orbit.
(*iii*) To book only work which is of a type the aircraft can undertake.

The ideal salesman will book the right field in the right place at the right time. Conversely, he must turn down work which will be uneconomic.

One method by which the sales agent can rationalise some of the planning problems facing him is by making differential charges, for example by charging according to the distance of the work from the centre of his orbit, by giving discounts for early bookings and for definite bookings for three or four applications. Special quotations may also be offered for large acreages.

There is scope in our Industry for this greater flexibility in price structure. If the planner is to overcome the many problems facing him, he may often have to spend additional money in the process and it is highly desirable that the farmers should carry the penalty—or the benefit—in the form of a price differential.

3. Pre-Operational Planning

3.1. CONTRACTUAL ARRANGEMENTS

Whether or not the operator takes part himself in the sales campaign, there will come a time when he must hand over a major part of the operation to local control—that is, to a ground supervisor, agent or merchant.

The merchant's record of bookings may take the form of a written contract with the grower. The operator may in turn have a contract with the merchant, written or verbal, or the merchant may act as an agent and the contract will be a direct one between operator and grower.

The legal and commercial issues involved in aerial agricultural work are complex and it is wise for the operator to have his contracts carefully prepared by those suitably qualified.

It is physically impossible for a pilot personally to inspect each field from the ground before treatment. The form of enquiry or contract completed by the agent must therefore give the maximum amount of information. This enables the pilot to find the field and also, if there is doubt about its suitability, it can be inspected by an expert well in advance of the aircraft's arrival.

One form of contract used by the author's company is shown in Fig. 4. With it is associated a Confirmation Form, completed at the time at which the order is confirmed, which calls for sketch maps to be drawn using a standard set of symbols. From the sketch maps, the local controller will prepare his instructions to pilots and markers, which will be referred to later in this paper.

Besides stating what he will do, the operator's agreement should state quite clearly what he cannot do.

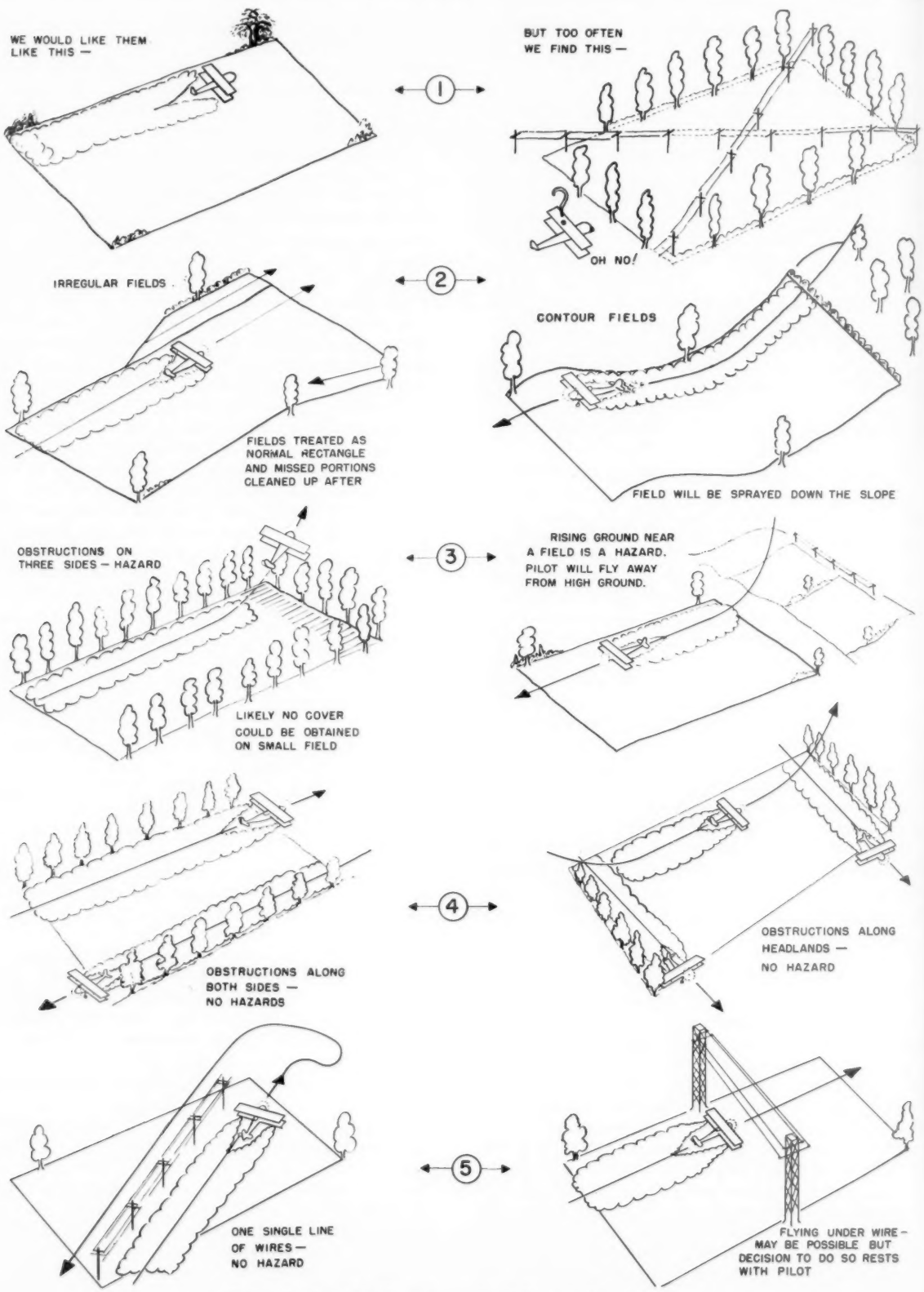

WE WOULD LIKE THEM LIKE THIS —
1
BUT TOO OFTEN WE FIND THIS —
OH NO!
IRREGULAR FIELDS
2
CONTOUR FIELDS
FIELDS TREATED AS NORMAL RECTANGLE AND MISSED PORTIONS CLEANED UP AFTER
FIELD WILL BE SPRAYED DOWN THE SLOPE
OBSTRUCTIONS ON THREE SIDES — HAZARD
3
RISING GROUND NEAR A FIELD IS A HAZARD. PILOT WILL FLY AWAY FROM HIGH GROUND.
LIKELY NO COVER COULD BE OBTAINED ON SMALL FIELD
4
OBSTRUCTIONS ALONG BOTH SIDES — NO HAZARDS
OBSTRUCTIONS ALONG HEADLANDS — NO HAZARD
ONE SINGLE LINE OF WIRES — NO HAZARD
5
FLYING UNDER WIRE — MAY BE POSSIBLE BUT DECISION TO DO SO RESTS WITH PILOT

FIGURE 3. An aid to hazard assessment for spraying aircraft.

AERIAL APPLICATION CONTRACT

FARMER'S COPY OF CONTRACT WITH MERCHANT

MERCHANT'S NAME & ADDRESS	FARMER'S NAME & ADDRESS

DETAILS OF ORDER

ACREAGE: (Subject to confirmation):	
CROP:	NUMBER OF APPLICATIONS:
PEST OR DISEASE: *(where applicable)*	APPLICATION RATE *per acre*
TREATMENT:	PRICE *per acre*
TREATMENT TO BE CARRIED OUT ON OR BETWEEN—	PERIOD WHICH MUST ELAPSE BEFORE HARVESTING:

ORDER

I herewith place my order for the above aerial application with the Merchant named in this Contract. I understand that this Order is subject to the terms and conditions overleaf, and also to official confirmation.

DATE

FARMER'S SIGNATURE

Map Reference No.—

ACCEPTANCE OF ORDER

This Order is accepted subject to the terms and conditions overleaf and to final confirmation.

Date—

For and on behalf of

Signed—

CONFIRMATION OF ORDER

This Order is hereby confirmed

Date..... *Merchant's Signature*.....

TERMS AND CONDITIONS

1. The area to be treated shall be indicated by the Farmer to the Merchant, his servant or his agent at least 14 days before commencement of the treatment. If the area is indicated less than 14 days before the proposed treatment date, a delay in the execution of the work may be inevitable.

2. The Farmer shall inform the Merchant, his servant or his agent of any obstacle or circumstance which might reasonably constitute a hazard to aircraft or to livestock, personnel or crops on the Farmer's land or on adjoining or neighbouring land. The Merchant shall not be responsible for any errors or damage arising out of incorrect information or direction given by the Farmer.

3. If, after the date of confirmation of the Contract to the Farmer, the total cost of materials and labour is increased by more than 5% then the price per acre stated overleaf shall be raised pro rata.

4. Should the acreage treated exceed that stated on the Confirmation Form, the Farmer shall pay for the extra treatment at the appropriate price per acre for the area actually treated, to the nearest whole acre.

5. The Merchant shall not be liable for variations between the amount of chemical used and the amount stipulated overleaf, provided that such variations are not more than 5%.

6. The Merchant and his agents undertake to use all reasonable care in applying the treatment, but no guarantee as to the efficiency of the treatment is given and all conditions and warranties implied by law are hereby excluded. On the basis that all reasonable care shall be taken, neither the Merchant nor his servants nor agents will be under any liability for loss of, or damage to, crops, timber, livestock and property of whatsoever kind or nature, and howsoever caused, on any land in the occupation of the Farmer, or any injury to the Farmer, his servants or his agents, or to any of their property.

7. The Merchant or his agent may refuse to carry out any part of the work which, in his opinion, might cause damage to aircraft, crops, livestock, game or property on land wheresoever situated or might cause personal injury to any person.

8. Any complaint relating to the work carried out under this order shall be made by the Farmer, in writing, to the Merchant within seven days of the date of treatment, failing which the Merchant shall be under no liability to rectify such work or pay compensation for loss or damage for which the Merchant might otherwise be liable hereunder.

9. In the case of edible crops sprayed with an organo-phosphorus insecticide, the Farmer shall not harvest any portion of the crop until the minimum period between the completion of spraying and harvesting shown overleaf has elapsed.

10. The Farmer shall have an authorised and responsible person available on the arrival of the aircraft's ground team, in order to point out to them the area to be treated. The Merchant shall not be responsible for any area treated in error if such a person is not available prior to treatment.

11. Notwithstanding anything herein contained neither party shall be held liable for any delay or failure to carry out this Contract in whole or in part by reason of an act of God, force majeure, the Queen's enemies, war, strikes, lockouts, labour disputes, accidents, civil war, floods, illness, the necessity of compliance with a statutory instrument or unavailability of any material, machine or aircraft or personnel.

12. Any dispute or difference between the Farmer and Merchant arising out of the Contract shall be referred to a single arbitrator in accordance with the provisions of the Arbitration Act, 1950 or any statutory modification thereof.

FIGURE 4. Aerial Application Contract. On the left the contract form and on the right the terms and conditions which appear on the back of the contract.

He cannot be responsible for the results of the chemical treatment and circumstances may plainly occur through no fault of his own—for example—mechanical failure or weather—which will make it impossible for the operator to complete the job precisely at the required time. It is doubtful to what extent every eventuality can be covered in a contract and a fair measure of goodwill is required on all sides.

One other important matter associated with this stage of planning is the provision of adequate insurance. The operator should ensure that he has cover against both normal third party risks and chemical liability risks. This type of insurance is not a legal requirement but the onerous legal responsibilities laid on the operator make it desirable.

3.2. THE SUPPLY PROBLEMS

Once the pattern of work has been established, those concerned with planning the operation must arrange for the supply of the various materials required—chemicals, fuel, oil and water.

3.2.1. *Chemical*

The supply of chemical is usually the responsibility of the agent but the operator must ensure that the material is where he wants it at the right time. The supplier must not merely arrange to deposit the chemical in a corner of the field—the wind may change and the material may be wanted at the other end, or the job may be cancelled or delayed. Trailers or lorries are expensive to run, but valuable time will be wasted if the chemical is not mobile.

When water-based sprays are required, the operator or merchant must see that suitable water supplies are available. A low-capacity tap in the next field will be inadequate if a high speed job is required. If dyke or ditch water is used it will probably be contaminated and filters must be used.

Courtesy of "The Farmer's Weekly"

FIGURE 5. A Land Rover Loader lifting fertiliser into the hopper of a Tiger Moth Aircraft.

3.2.2. *Mixing and Loading of Chemical*

Special loaders for fertilisers are, of course, a necessity if quick turn-rounds are to be achieved. The author's company has experimented with several designs of varying capacities. Those illustrated include a Land Rover rig of about 5 cwt. capacity, a one ton Morris loader and an Austin three ton loader, capable of lifting

FIGURE 6. Three Loaders developed by Crop Culture for top-dressing work. The centre vehicle is a one ton Morris. The other two are three ton Austin vehicles.

FIGURE 7. A tanker which holds chemical and mixing liquid for sprays, here shown at work with a Djinn helicopter.

up to one ton (*see* Figs. 5, 6 and 7). The Morris truck has proved the most versatile under United Kingdom conditions. An unskilled driver can learn to operate it without difficulty. Here the hopper discharge into the aircraft is operated by hand but other types can be controlled by the driver from the vehicle cabin. One difficulty which often arises in the field is that loaders are bogged in wet ground; four-wheel drive is a necessity. Sacks, straw or metallic tracking are often useful on wet ground. Another form of loader has been designed to fit on the farmer's tractor.

Chemical tankers for the transport and mixing of spray materials have also been developed. Many of the chemicals in common use will not remain in suspension and must be freshly mixed before use. This can be achieved by hand stirring or by recirculation with a pump in an open-top drum. A more satisfactory technique is the use of a specially designed mixing tank, for instance a 100 gallon capacity tank, in which the materials are recirculated by a small capacity petrol driven pump. The tanker vehicle may also carry several hundred gallons of the carrier liquid. Provision should also be made for pumping the liquid mixture at high speed into the aircraft tank—a full load should ideally be loaded in half a minute or less.

3.2.3. *Fuel*

This is one of the most difficult aspects of advanced planning. Fuel and oil must be ordered well in advance if they are to be delivered to the landing strip in good time. Unfortunately farmers are often unable to give the operator the degree of advance warning required, and the decision as to the acreage to be treated may have to be left until the last moment. Furthermore, if large quantities of fuel are required, there is the difficult problem of transport and storage. Licensing authorities are naturally reluctant to agree to drums of aviation spirit being stored in ordinary storage premises and the cost of special buildings is prohibitive.

Finally, if the planner or the farmer over-estimates fuel requirements, he has the almost impossible task of trying to dispose of the surplus. Special vehicles are required to transport it and there is nowhere to store it. It can be drown-graded, but at a 50 per cent loss in price. Much as all those concerned would like to help, it would seem that the rigid and unimaginative attitude of H.M. Customs, together with Air Registration Board regulations, have erected a most potent barrier to operational efficiency. Here is a matter calling for detailed study by the Industry as a matter of urgency. No easy solution presents itself—tanker vehicles and trailers may be worth consideration, or special dispensation of storage regulations. But there is no doubt that present practice cannot be allowed to continue.

3.2.4. *Summary*

These three aspects of supply—chemical, loading and fuel—must all be examined in the closest detail before the campaign begins. The limitations imposed on United Kingdom operations by the scarcity of "flyable" days make it essential that no time is lost through failure on the ground. As little as thirty seconds added to every turn-round in the top dressing phase by a poorly-designed hopper release on the loader has a serious effect when it is considered that one aircraft may make as many as 1,500 turn-round landings and take-offs per season. These few seconds, multiplied over the season, could have produced another £250 in revenue per aircraft.

4. Elements of the Unit

We may now consider the characteristics of the actual work unit. Its size and composition will vary according to the requirements of the job. Two aircraft of the Tiger Moth or Auster type may be operated from one strip, when the volume of work justifies it, with consequent high utilisation of ground equipment and personnel. This arrangement has worked well, particularly during the top dressing phase when sorties are of short duration. There may be other occasions when

duplicate ground vehicles for a single aircraft might be justified—for example when the centres of operation are widely scattered.

On still other occasions, when the job is a small or isolated one, the pilot may have to handle the work virtually on his own.

The most important element of all in the Unit in the field is, of course, the individuals of which it is composed—the pilot, driver, engineers and markers.

4.1. MARKERS

It is sometimes supposed that markers can be hurriedly recruited from the local Labour Exchange and need no special skills. This is far from true and inadequate marking can be the cause of major delays, serious accidents or an unsatisfactory treatment. It is primarily the responsibility of the markers to see that the pilot treats the right field and does so accurately.

Markers must be thoroughly briefed—the author's own company produces comprehensive notes for this purpose—and there must be close liaison with the pilot on the job so that the one fully understands the signals made by the other.

Markers must also have satisfactory transport—a bicycle cannot keep pace with an aeroplane and the marker must be in position ahead of the arrival of the aircraft. On a high pressure spraying campaign, where fields are scattered, up to six markers per aircraft may be needed.

4.2. DRIVERS AND LOADERS

The driver, who will assist with the mixing of the chemical and with loading it into the aircraft, must also understand thoroughly the need for speedly turn-round times on the ground. A good driver is a key member of the team.

In the top dressing phase it is usually desirable to employ an additional man to assist with loading the fertiliser into the aircraft and into the loader.

All those involved in the mixing of the chemical must understand the nature of their job and its hazards. Poisonous chemicals are a very serious danger to those who handle them carelessly and the operator has a heavy responsibility in seeing that this is understood.

The regulations laid down by the Government in its booklet "Safe Use of Chemicals on the Farm" should be read by all concerned. Specialist notes should be prepared for the more commonly used toxic chemicals.

It is wise for all personnel handling chemicals to carry a letter addressed to a doctor so that if they are found unconscious, poisoning can be suspected. Suitable antidotes can also be carried.

An Air Registration Board circular issued in April 1959 commented in detail on this subject, and on the matter of corrosion of the aircraft structure.

4.3. ENGINEERING AND MAINTENANCE STAFF

Some operators plan for a fitter to work permanently with the Unit in the field, seeing to the daily inspections and maintenance and undertaking minor repairs. However, the more usual arrangement is for the pilot to take responsibility for routine maintenance, perhaps with periodic inspections by a licensed engineer to ensure a satisfactory standard. Scheduled maintenance by qualified engineering personnel at least at fifty hour intervals, and a further and more detailed check at 150 hours, is necessary.

A heavy responsibility rests on the pilot and he should therefore be supplied with a written maintenance schedule to assist him. Air Registration Board Circular No. 56 of March 1959 advises agricultural operators, in their own interests, to submit their maintenance schedules to the Board for approval.

4.4. THE PILOT

The pilot will lead the Unit in the field, working closely with the agent's representative or ground supervisor and, if he has not been directly concerned with the planning at all stages, he should be given full information. He must have knowledge of the work targets and the sales programme. Ideally a clear delineation should be made between his responsibilities and those of the ground supervisor or merchant's representative. However, the pilot must essentially be an individual with a resourceful and flexible character, even-tempered and energetic—in short a paragon who will interpret the requirements of the job in a sensible way and make up for the short-comings of advance planning.

4.5. CREW ACCOMMODATION

Crews must have comfortable accommodation and regular meals. It is difficult to arrange these at the average hotel at times suited to the average aerial operation. A caravan on the landing strip where snacks and tea can be produced is one solution.

4.6. CREW REST PERIODS

It is unlikely that in the United Kingdom pilots will often reach the statutory limits of time in the air. Despite this, the work will frequently be extremely fatiguing for the pilot and for other personnel and a special study of this matter, and of pilot fatigue in particular, is long overdue.

4.7. RADIO

Good communication between everyone taking part in the operation is vital and radio is a useful addition to the Unit, with a receiver on the landing strip in contact both with the merchant's headquarters and with the markers in the field. It has not proved necessary to fit radio in the aircraft and, in fact, where it has been used, considerable loss of production has been experienced through unserviceability. The added ancillary equipment such as battery and generator are not only heavy but expensive and costly to maintain.

5. Planning the Work of the Unit

Having satisfactorily achieved his aim of finding work for the Unit and arranging for it and its attendant supplies to be in the right place at the right time, it remains for the operator to ensure that the pilot treats the correct field to timetable and that the job is properly recorded.

5.1. WORK SCHEDULE

The ideal form of work schedule for the pilot is a series of maps cut from a one inch to the mile Ordnance Survey and pasted in a notebook with accompanying notes of hazards, crops, and so on. Sketch maps will also be necessary. By numbering the various jobs, the planner has a simple method of ensuring that the work is undertaken in the correct sequence.

5.2. WORK RECORDS

Three routine records which assist the aerial agricultural planner are:

(*i*) The daily flying sheets giving (*a*) the time of day when flying was possible, (*b*) the number of hours flown in the day, (*c*) the reasons for non-flying—unserviceability, and so on, (*d*) the work completed—acreage, crop, chemical used and application rate.

(*ii*) The acreage return, compiled from the daily flying sheet or the job sheet or invoice. This may provide for a signature from the customer confirming that the job was completed satisfactorily.

From this information the operator can calculate acres per hour, which is a useful measure of work efficiency. He can also compare the ratio between productive and unproductive flying. Knowing his cost per flying hour, he may well find that the gross profit from a large acreage will be below that from a less spectacular area being treated at a far higher rate of efficiency.

6. Reserves

No responsible company would put an aircraft in the field without spare parts and equally it must make adequate provision in terms of reserves. Admittedly this is a difficult matter for the small operator; it is galling for him to have to retain an aircraft on the ground, doing nothing to earn its keep, at a time when there may be an outcry for more capacity. But if an accident happens, or his aircraft is withdrawn from service for maintenance, the ability to fulfil his contracts immediately with the reserve aircraft will reap great dividends in terms of good-will. Reserves must extend beyond the aircraft to the vehicles and personnel, including pilots, drivers and markers.

7. Accidents

Provision must, of course, be made for action in the event of accident. Crashes are, regrettably, inevitable in any form of aviation and agricultural work is no exception, but there is far more opportunity in this specialist business than in others for the aircraft to have a high degree of built-in "crashworthiness." This, and the wider subjects of safety and pilot fatigue are not matters for this paper.

It is, however, necessary that those in the field supply the following detail accident information which will be required by the operator himself, the Ministry of Aviation and the Underwriters:

(*i*) registration letters of aircraft,

(*ii*) name of pilot,

(*iii*) date and time of accident in G.M.T.,

(*iv*) duties of aircraft at time of accident—spraying, ferrying, training,

(*v*) map reference of position of aircraft and reference to some easily defined geographical point,

(*vi*) nature of injury to personnel,

(*vii*) the cause of the accident so far as is known,

(*viii*) a detailed description of the damage to the aircraft,

(*ix*) any third party damage.

8. Conclusions

It is clear that the operator in the United Kingdom has a most demanding task if he is to plan his programme satisfactorily. Not only the operator himself but the merchant and all concerned with aerial agriculture—and here we must include the chemical companies, the oil companies, the Ministries of Agriculture and Aviation and many others—are presented with problems and difficulties of an exacting kind.

The primary aim of planning is improved profitability, but others beside the operator himself must find that the effort required to achieve success in aerial agriculture in the United Kingdom is barely balanced by increased turnover.

Yet we are now approaching the time when sound planning will not only be evidence of good management, but will be mandatory, under the law, before an operator can obtain the necessary permission to carry on his business.

There is only one way in which operators can afford to plan their work to the high standard of efficiency it demands, and this is by increasing profit margins. The farmer knows that by treating his crop from above, instead of dragging a machine through it, he may save £6 or £7 per acre, and the time has come for the operator to use this fact to establish for himself a price structure closer to the true costs of putting a Unit into the field.

REFERENCES

Papers read at the International Aviation Conference, Cranfield, September 1959. *To be published.*

Some Factors Affecting the Economics of Agricultural Aviation in Great Britain. Denis Nahum.

Economic Factors Affecting Agricultural Aircraft Operation. N. D. Norman.

Agricultural Aviation in England—Low Flying Techniques and Safety. J. M. McMahon.

TECHNICAL NOTES

Solar Probes

by

S. W. GREENWOOD, B.Sc., M.Eng., A.F.R.Ae.S., A.M.I.Mech.E.

(*Member of Council, British Interplanetary Society*)

THE Soviet Deputy Premier, Mr. Anastas Mikoyan, is reported to have stated recently that Russia has a missile ready to "visit the Sun."

The Russians have been achieving a notable series of "firsts" in space exploration, and this statement may have led some to speculate on whether they will be the first to reach the Sun.

It is, of course, strictly impossible to talk in terms of hitting or reaching the Sun, as it has no solid surface. Indeed the streams of matter and radiation it emits travel out into space beyond the orbit of our planet. However, for practical purposes the Sun is opaque over a diameter of just under a million miles, and this constitutes a generally agreed boundary for purposes of such a study as this.

Conditions on the bodies that constitute the Solar system are dominated by the Sun, and this alone would justify the continued examination of its behaviour. Additional justification is provided by the fundamental knowledge of matter obtained through observing the Sun and its radiated energy.

In the discussion that follows it is assumed that a vehicle sent close to the Sun would be suitably protected against the absorbtion of an excessive amount of radiant energy. In calculating the amount of incident energy, the Sun may be taken as a black-body emitter having a surface temperature of about 6000°K. The incident energy in the vicinity of the Earth's orbit is then found to be about one-sixth of a horsepower per square foot, but it will vary inversely as the square of the distance of the vehicle from the Sun, and for flights approaching the Sun particular care will need to be taken to provide for a surface of high reflectivity on the side exposed to solar radiation. The thermal control of instrumentation will also be of great importance.

A vehicle intended to hit the Sun can be expected to experience only inevitable doom, though in the remote future advanced technology may permit journeys into its close atmosphere.

For some years to come it seems likely that chemical rockets will be used for space exploration. The most suitable orbits for such vehicles when the objective is to travel as far as possible with respect to the Sun are ellipses touching the Earth's orbit, as shown in Fig. 1. The vehicle experiences operation of its propulsive system only during the initial period when it acquires a velocity sufficient for escape from the Earth's gravitational field and entry into the orbit around the Sun. The launching is in the direction of the Earth's motion around the Sun for entry into an elliptic orbit outside the Earth's orbit, and against the direction of the Earth's motion for entry into an elliptic orbit inside the Earth's orbit. Probes intended to approach the Sun therefore will follow orbits of the second category.

Two probes that functioned primarily for exploration of the space between the Earth and the Moon are now in orbits of the first category, but no data may be obtained from their paths as their transmitters ceased to function after passing the Moon. These probes are the Russian Lunik I and the American Pioneer IV.

The first attempt to approach closer to the Sun was to have been made last June by the Americans, but the plans were cancelled. The rocket was to have been launched into an elliptic orbit that touched the orbit of Venus at its point of closest approach to the Sun at a time when the planet would have been there also. A further American probe was due to be sent to the vicinity of the orbit of Venus in mid-December 1959. It was intended that conditions in space during the flight should be explored, and so the probe was essentially a solar one rather than a planetary one.

An attempt to relate the vehicle performance requirements to the journey undertaken has been made in Fig. 2. The velocity to be reached by the instrumented payload when free of the Earth's atmosphere is related to the closest approach to the Sun, for orbits lying within the Earth's orbit, and to the farthest distance from the Sun, for orbits lying outside the Earth's orbit.

For purposes of comparison the variation in the location of the nearer planets relative to the Sun is also indicated.

The lowest value of the velocity requirement is that for escape from the Earth and entry into the Earth's orbit around the Sun. The figure for this is 6·9 miles/second. For entry into any other orbit around the Sun the velocity requirement is increased.

For journeys outside the Earth's orbit the increase arises from the need to overcome the influence of the Sun's gravitational field. Lunik I and Pioneer IV do not voyage far outside the Earth's orbit, and a velocity of 7·0 miles/second is sufficient. The velocity requirement increases with increasing distance from the Sun, and approaches asymptotically the value of 10·3 miles/second at infinity, a situation that corresponds literally to escape from the Solar system.

For journeys inside the Earth's orbit the increase in velocity requirement as the Sun is approached more closely arises from the need to reduce the velocity of the probe

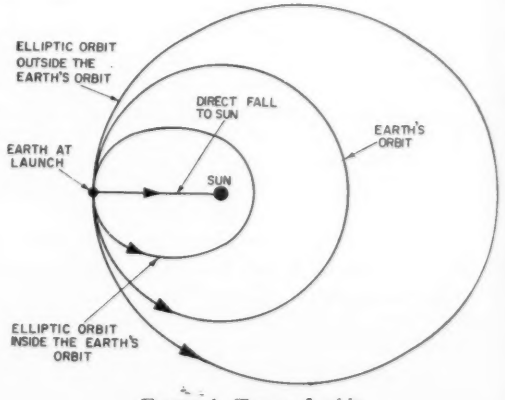


FIGURE 1. Types of orbit.

Received 11*th December* 1959.

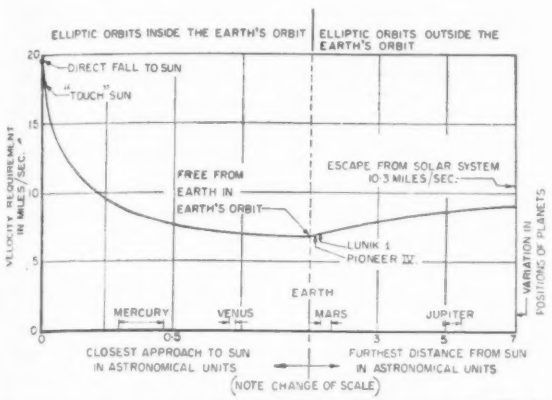


FIGURE 2. Velocity requirement for vehicle to enter elliptic orbit around Sun.

relative to the Sun in the vicinity of the Earth's orbit and so permit the probe to fall inwards toward the Sun. In the limit, a velocity of 19·8 miles/second will counteract the effect of the Earth's motion and the probe will fall directly into the Sun.

The Sun is comparatively large relative to the distance separating it from the Earth, its diameter being about one hundredth of the distance, and the velocity requirement for entry into an ellipse that "touches" the Sun is therefore usefully lower than that for the direct fall. The reduced figure is 18·1 miles/second.

It will be seen from Fig. 2 that the curve is fairly gradual in the region of the Earth's orbit, and that it becomes progressively more steep as orbits close to the Sun are considered. Probes to the region of the inner planets, Venus and Mercury, can therefore be attempted without much increase in the vehicle performance requirement over current probes capable of escaping from the Earth. A velocity of 10·3 miles/second employed on a journey inside the Earth's orbit would permit an approach to a distance of about one-fifth of an astronomical unit from the Sun. This corresponds to the vehicle performance required for escape from the Solar system, and the probe will travel well within the orbit of Mercury and sufficiently close to the Sun to permit very useful research to be carried out.

In a recent paper, Edelbaum ("Some Extensions of the Hohmann Transfer Maneuver," *A.R.S. Journal*, November 1959) has shown that for approaches closer to the Sun than one-fifth of an astronomical unit, the velocity requirement may be reduced by first entering an orbit outside the Earth's orbit, and then carrying out a velocity reduction when the vehicle is at its farthest distance from the Sun, permitting it to fall in toward the Sun. An extreme example of such a manoeuvre would be to escape completely from the Solar system and then perform an infinitesimal velocity change to permit the vehicle to make a direct fall to the Sun.

In theory, then, a velocity of 10·3 miles/second is all that is required in order to range completely through the Solar system. The disadvantage of the techniques using long distance flights outside the Earth's orbit is that the flights will take longer than those proceeding directly within the Earth's orbit, and for this reason are not likely to find favour.

What, then, are the prospects for the near future? The author has made a tentative attempt at assessing the possible types of vehicle and the size of useful payload that could be carried for particular orbits. For an orbit close to the Earth's orbit a three-stage vehicle with a payload of hundreds of pounds is feasible. For an approach to within one-fifth of an astronomical unit from the Sun or to escape from the Solar system a four- or five-stage vehicle is required, and a payload of tens of pounds would be feasible. For a direct fall to the Sun, an eight-stage rocket would be required, and the payload would be negligible in the present state of the art.

Unless there are significant developments in the direction of radically new propulsion systems, it seems that for some years to come proposals for probes to "visit the Sun" must be interpreted as referring to vehicles that will travel inside the Earth's orbit, and not to direct contact with the Sun.

It is a sobering thought that it is more difficult to reach the Sun than to set off on a journey to beyond the Solar system.

(Correspondence on this note is invited—Ed.)

High Speed Flow Through Perforated Plates

by

P. G. MORGAN, B.Sc.(Eng.)

(Department of Mechanical Engineering, University of Manchester)

THE FLOW THROUGH porous screens has been widely studied from both the theoretical and experimental points of view. The most widely used types of screen are the wire mesh and the perforated plate, and the majority of the literature has been concerned with the former. Several attempts have been made to correlate the parameters governing the flow through such screens, *i.e.* the pressure drop, the flow conditions and the geometry of the mesh.

For the sharp-edged perforated plate, however, the problem is simplified, since the internal flow losses are smaller and the relative extent of the jets and wakes can be predicted, the sharp edges determining the points of jet formation. Considering a simple model of the flow, we have a jet of area cA_o downstream surrounded by a wake of area $A_b+(1-c)A_o$ where

A_o area of the orifice in the plate

A_b area of the plate itself

i.e. A_o+A_b total projected area of the screen

c coefficient of contraction of the jet.

The relative extent of the jets and wakes is governed by the solidity ratio s of the plate, where $s=\dfrac{A_b}{A_o+A_b}$ and the coefficient of contraction, c.

Received 18th September 1959.

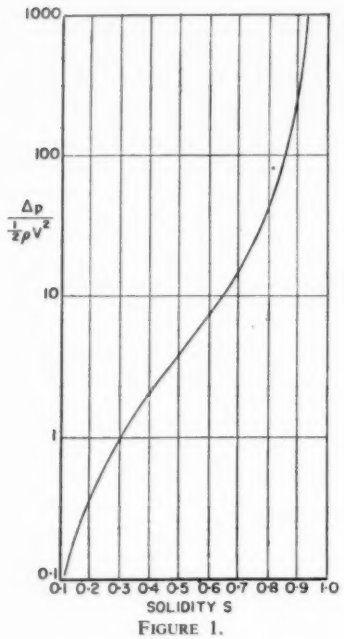


FIGURE 1.

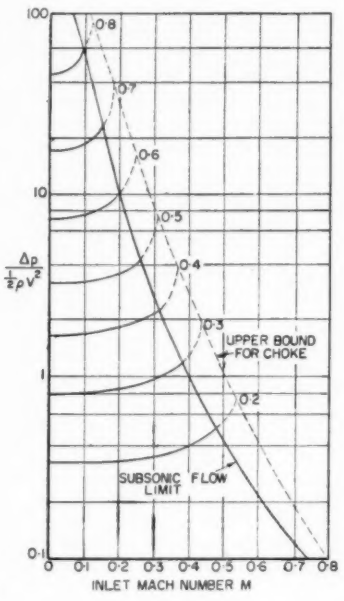


FIGURE 2.

Weinig[1] has given the results of tests on strip screens and shows that the mixing of the jets and wakes to form a uniform stream gives a loss coefficient

$$\frac{\Delta p}{\frac{1}{2}\rho V^2} = \frac{[1-c\,(1-s)]^2}{c^2\,(1-s)^2}$$

assuming incompressible flow with zero wake velocity. The coefficient of contraction, c, has been determined by von Mises[2] and Rouse[3], and, using their data, the curve of pressure loss coefficient against screen solidity is shown in Fig. 1. This has been substantiated by experiment.

With the flow through wire mesh screens, the Reynolds number (Re), based on some function of the screen dimensions, is of major importance in determining the pressure loss coefficient. For perforated plates, however, the pressure loss coefficient is practically independent of Re over a very wide range, and only begins to vary at low values, when the coefficient increases.

The problem of high speed flow through perforated plate screens has been studied by Cornell[4] who estimated the compressibility effect at high approach Mach numbers by generalising the analysis of the low Mach number case and taking account of the effect of the approach Mach number M on the contraction coefficient, c. No general theoretical treatment of the relationship between c, s and M is available, but using experimental discharge coefficients for the flow of air through sharp-edged orifices, obtained by Grey and Wilsted[5], Cornell has given curves of pressure loss coefficient ($\Delta p/\frac{1}{2}\rho V^2$) against approach Mach number M for different values of the screen solidity; these are reproduced in Fig. 2.

The subsonic flow limit curve is the locus of conditions at which the jet velocity is sonic; the "upper bound for choke" corresponds to sonic velocity in the screen openings, and actual choking conditions occur somewhere between these curves. No general method of estimating these conditions is available, and the pressure loss coefficient curves are shown as dashed lines between these two limits, since the one-dimensional flow basis of the prediction cannot be used for a Mach number of the jet behind the screen greater than unity, and additional supersonic flow losses resulting from shock waves are not taken into account.

Experimental data on high speed flow through perforated plates has not been available to confirm the theoretical predictions of Fig. 2. A series of tests has therefore been carried out on four perforated plates, details of which are given in Table I. The tests were carried out by mounting the plate specimens in a duct through which air is drawn at high speed; details of the experimental equipment and the measuring techniques have already been given (*see* Ref. 6).

Figures 3 and 4 show the results of the tests; the theoretical curves due to Cornell are drawn for the appropriate solidity of the screen and the corresponding experimental points inserted.

It is obvious that there is considerable divergence between the theoretical prediction and the actual experimental points. Plate 1, with the largest diameter holes, shows a close agreement, but with some difference in the value of M at which the rapid change in pressure drop coefficient occurs. Plate 3 has the same solidity s as Plate 1, but the experimental points lie considerably above the

TABLE I

Plate number	*Thickness (in.)*	*Hole Diameter (in.)*	*Distance between centres of holes (in.)*	*Solidity s*
1	0·042	0·250	0·363	0·56
2	0·026	0·062	0·055	0·69
3	0·021	0·125	0·187	0·56
4	0·047	0·150	0·181	0·37

Note: All plates have holes drilled in an equilateral triangular pitch.

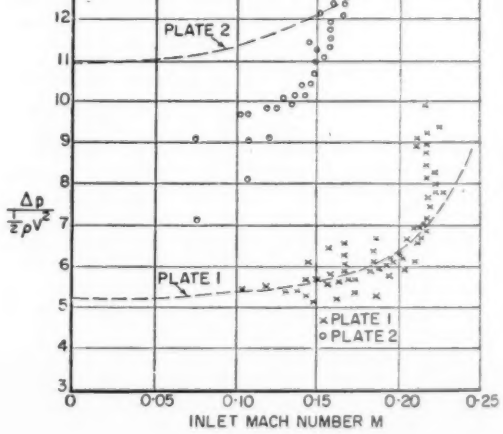


FIGURE 3.

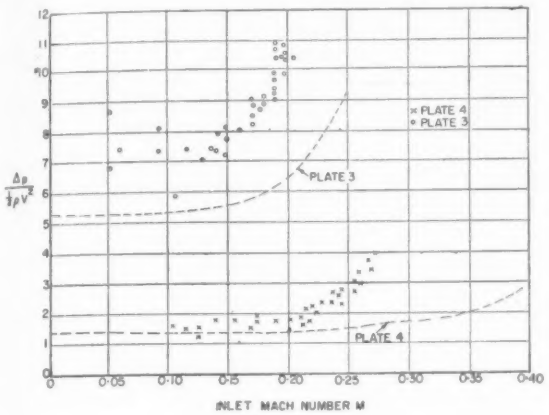


FIGURE 4.

theoretical curve, and there is little comparison between the experimental results of Plates 1 and 3, despite their identical solidities. Plate 2 also shows a considerable difference between the theoretical and experimental values, and Plate 4, despite the fact that the choke limit has not been reached, shows the inadequacies of the theory.

Cornell's analysis is insufficient for conditions approaching the choke limit, and an alternative approach is necessary. It is probable that an important factor governing the pressure drop is the plate thickness, and it is proposed to carry out a number of tests on perforated plates of the same hole geometry but with plates of different thickness. In addition, a further comparison is required for plates of the same solidity, but with different diameters and spacings of the holes, since it is clear that the solidity is not the only criterion governing the flow at high speeds. The results for Plate 3 indicate that further tests are necessary for high solidity, small hole diameter plates, especially in view of the use of such plates for boundary layer suction applications.

ACKNOWLEDGMENT

The author wishes to thank Mr. R. K. Srivastava for his assistance with the calculations and Mr. A. Frith for his assistance with the experimental work.

REFERENCES

1. WEINIG, F. S. (1947). A.M.C. Wright Field Tech. Report F-TR-2148-ND, 1947.
2. VON MISES, R. (1917). *ZVDI* 61, p. 447, 469 and 493, 1917.
3. ROUSE, H. (1946). *Elementary Mechanics of Fluids*, John Wiley, p. 58, 1946.
4. CORNELL, W. G. (1958). *Trans. of the American Society of Mechanical Engineers* 80, 4, p. 791, 1958.
5. GREY, R. E. and WILSTED, H. D. (1948). N.A.C.A. T.N. 1757, 1948.
6. MORGAN, P. G. (1959). High Speed Flow Through Wire Gauges. *Journal of the Royal Aeronautical Society* 63, p. 474, August 1959.

The Buckling of a Circular Plate With a Concentric Circular Hot-Spot

by

K. I. McKENZIE, PH.D.

(*Royal Aircraft Establishment*)

IF A CIRCULAR PLATE has a concentric circular hot area, there is a critical temperature for this area at which the plate buckles. This temperature is calculated in this note for the case of a clamped plate supported in such a way that the radial stress in the cold part obeys the inverse square law.

1. INTRODUCTION

If a clamped circular plate has a concentric circular area raised to a uniform temperature, there is a constant radial compression in the hot part, while the radial compression in the cold (annular) part decays as the distance from the centre increases. By suitably supporting the edge of the plate it is possible to arrange that the stresses in the cold part obey the inverse square law. Assuming these conditions, this note combines the solution given by Mansfield[1] for the buckling of an annular plate with that given by Timoshenko[2] for a circular plate to obtain the critical temperature for buckling.

NOTATION

α coefficient of thermal expansion
E Young's modulus
ν Poisson's ratio
t plate thickness
$D=Et^3/12(1-\nu^2)$
r, θ, z cylindrical polar co-ordinates
ψ angle between normal to deflected plate at any point and z-axis
r_1 radius of plate
r_0 radius of hot area
T temperature difference between hot area and rest of plate
σ_r radial stress
β buckling parameter$=\dfrac{t\alpha ET r_0^2}{2D}$
$\rho=r/r_0$
$\mu=r_1/r_0$
$\phi=\sqrt{(\beta-1)}$
J_0, J_1, J_2 Bessel functions of the first kind and of orders 0, 1, 2 respectively.

2. ANALYSIS

The radial stress in the hot area is a uniform compression $\alpha ET/2$. Thus using the result of Timoshenko[2], the differential equation for the hot area is:

$$\frac{d^2\psi}{d\rho^2}+\frac{1}{\rho}\frac{d\psi}{d\rho}+\psi\left(\beta-\frac{1}{\rho^2}\right)=0, \quad . \quad . \quad (1)$$

for which the solution is:

$$\psi=A_0 J_1(\beta^{\frac{1}{2}}\rho), \quad . \quad . \quad . \quad (2)$$

since ψ must be zero at the origin.

Received 26th October 1959.

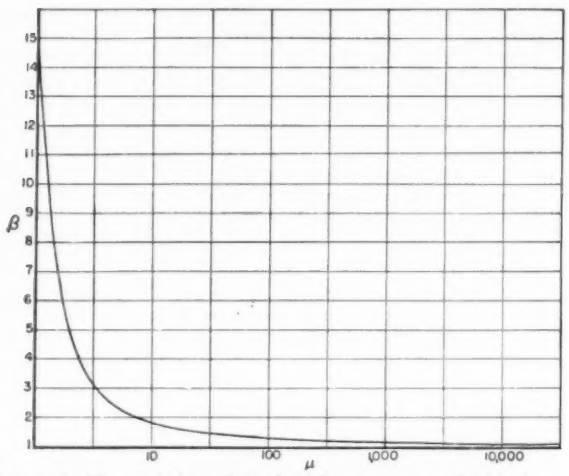


FIGURE 1. The variation of the buckling parameter β with the ratio of the radius of the plate to the radius of the hot-spot, μ.

Now if the edge of the plate has a supporting member of section area $r_1 t/(1+\nu)$, the radial stress in the annular part is the same as if the plate extended to infinity, namely a compression $\alpha E T r_0^2/2r^2$, and the differential equation for this part of the plate is:

$$\frac{d^2\psi}{d\rho^2}+\frac{1}{\rho}\frac{d\psi}{d\rho}+(\beta-1)\frac{\psi}{\rho^2}=0. \quad . \quad (3)$$

Assuming β to be greater than one, the solution to this equation is best written

$$\psi=A_1 \sin(\phi ln\rho)+A_2 \cos(\phi ln\rho) \quad . \quad . \quad (4)$$

Using suffix 1 for the value of ψ given by equation (2) and suffix 2 for that given by equation (4), the boundary conditions are:

$$\psi_2=0 \quad \text{on } \rho=\mu \quad . \quad . \quad . \quad (5)$$

and

$$\psi_1=\psi_2, \quad \frac{d\psi_1}{d\rho}=\frac{d\psi_2}{d\rho} \quad \text{on } \rho=1. \quad . \quad (6)$$

These conditions express the facts that the plate is clamped on $\rho=\mu$, and that the slope and bending moment are continuous on $\rho=1$.

Substituting from equations (2) and (4) and eliminating the arbitrary constants A_0, A_1, A_2, the following condition for buckling is established:

$$\phi\frac{J_0(\beta^{\frac{1}{2}})+J_2(\beta^{\frac{1}{2}})}{J_0(\beta^{\frac{1}{2}})-J_2(\beta^{\frac{1}{2}})}=-\tan(\phi ln\mu).$$

3. RESULTS AND CONCLUSIONS

Figure 1 shows the variation of the buckling parameter β with μ plotted on a logarithmic scale for convenience of presentation. It can be seen that β varies from the value for a uniformly compressed circular plate when $\mu=0$, to the value (unity) obtained by Mansfield for an infinite annulus with its inner edge clamped as μ becomes infinite. It is interesting to note that, as in the case of the annular plate, the limiting value as μ tends to infinity is of little practical significance owing to the extreme slowness with which β tends to unity.

REFERENCES

1. MANSFIELD, E. H. On the Buckling of an Annular Plate. *Quarterly Journal of Mech. and App. Maths.* To be published.

2. TIMOSHENKO, S. (1936). *The Theory of Elastic Stability.* McGraw-Hill, p. 367, 1936.

Operational Problems of Take-Off and Landing—A Correction

In the Discussion following Operational Problems of Take-Off and Landing, published in the December 1959 JOURNAL, Captain A. P. W. Cane was unfortunately misquoted. The first paragraph of his remarks on page 695 *should* read as follows:—

Captain A. P. W. Cane (B.O.A.C.) said he would like to take both Mr. Pike and Captain Prowse up on one point. They had both emphasised the inability of the human being properly to assess his approach and landing from the visual cues presented to him in clear weather and yet they followed on by saying that they required a visual means of monitoring an automatic landing, in order that the pilot might be able to consider the operation safe. This seemed to be a contradiction in terms, especially in the case of the televiewer which gave vastly inferior visual cues to those available on a normal visual approach and landing, and yet was to be used to monitor the automatics. Surely, if the pilot was given a "black-box produced" inferior visual picture he would find it impossible to monitor the automatic landing with any degree of confidence. The only excuse for superimposing a visual monitor on an automatic landing would be the production of a completely unambiguous visual picture so that no errors of judgment could be made—it had so far proved impossible even in perfectly clear weather, to present such a picture to the pilot.

Graduates' and Students' Section

Lecture

The first lecture of the Spring Session was given by Wing Commander F. Latham, M.D., O.B.E., R.A.F., on Wednesday 13th January, on "Aviation Medicine in the Space Age".

During the war years much work was carried out on the physiological effects of prolonged acceleration encountered in aircraft manoeuvres. More recently during high speed flight, attention has been drawn to the tolerance of the human body to short duration accelerations experienced during seat ejection vibration and linear impact. In all cases, studies started by considering the body/seat combination as a single double-mass spring-coupled system, the spring effect being produced by the seat cushion and innate springing of the human torso, and the two masses at either end of the spring being the seat mass and the head and upper trunk mass. When a force was applied to the seat the resultant acceleration and rate of change of acceleration on the mass depended on the elastic characteristics of this system. In the absence of critical damping the spring of the man and cushion was compressed beyond the equilibrium condition and during this period, when there was a relative lag on the movement of the man, surplus kinetic energy was stored by the seat. At a later stage this excess energy was shared between the mass of the man and the mass of the seat, and internal oscillations about the common c.g. were induced. It was considered that the amplitude of the oscillations and peak acceleration on the man's body would be related to the ratio of the natural period of the human frame in the vertical axis and the time function of the applied force. The duration of the seat acceleration was governed largely by engineering considerations and, in the seat ejection case, by the ejection velocity necessary. If the force rose to a maximum in much less than the predominant natural period of the system then an overshoot in acceleration occurred. A similar peak acceleration rising to its maximum more slowly in a single or simple multiple of the predominant natural period of the system would cause a minimal overshoot of acceleration.

Using this theory a number of experiments were undertaken in order to develop a suitable seat pack or cushion: the fundamental resonant frequencies of the seated human body were determined when subjected to a steady vibration acting from seat to head with various types of cushion arrangements. In addition, laboratory impulse tests indicated which resonant frequencies predominated and gave information on the damping characteristics of these various cushions. The results showed that significant forced resonances were apparent at approximately 5, 8 and 17 to 20 c./sec. At the lower frequencies there was a marked whole body bounce, but at 8 c./sec. the hip/head resonance was most significant with a subjective sensation of blurring of the vision. With the introduction of springy cushions the whole body response at 5 c./sec. was accentuated while the natural frequency reduced, whereas the resonance at 8 and 17 to 20 c./sec. was reduced.

To test response to impact, the ejection seat carrying the subject was raised a distance of 6 in. up its own guide rails so that when suddenly released, it dropped against a concrete floor. In effect this applied an impact acceleration from which the body's response could be recorded. The resonant frequency induced with different types of cushions compared closely with the low frequency response observed when the body was subjected to a steady state vibration. Similar results were obtained when the body was subjected to single transient impulses applied by means of a sledge-hammer blow beneath the seat.

The fundamental body ballistic data derived from these experiments were fed into an analogue computer and the relative importance of the variables involved were then assessed. This provided data which could otherwise only be obtained by prolonged live experiments and thus the problem was reduced to its simplest form by the assumption of the double-mass spring-coupled system.

The aim of this work was to define as accurately as possible the upper human tolerance limits for short duration accelerations acting through the vertical axis of the body. This limit is seen to be governed by the force-time function of the ejector gun, the alignment of the body and the seat, and the dynamic characteristics of the seat pack under the occupant.

Wing Commander Latham concluded his interesting talk, which was illustrated by a colour film and slides, with a short resumé of the problems involved in the design of seat harnesses or linear deceleration studies. Experiments were carried out on a subject harnessed to a rocket-powered trolley which was accelerated along a track and then brought to rest in varying short distances. The resultant pressure on the abdomen, due to the retaining effect of the harness, was transmitted into the venous system and caused a shock wave to travel, against the flow, into the head and eyes where it resulted in haemorrhages in the soft tissues of the face—black eyes, and so on.

In the lively discussion which followed many questions were asked, ranging from the effect of radiation at high altitudes to the availability of subjects on which to experiment. The meeting ended with the lecturer being accorded a well earned vote of thanks for such an entertaining talk and also for making the journey from Farnborough in such severe weather.—W.G.W.

Annual General Meeting and Film Show

The Annual General Meeting of the Section will be held at 4 Hamilton Place, London W.1, at 7.30 p.m. on Wednesday 24th February 1960. Coffee and biscuits will be served from 7 p.m.

Agenda

1. To consider and approve the minutes of the previous Annual General Meeting.
2. To consider any business arising from these minutes.
3. To receive the report of the Committee on the activities of the Committee and Section during the past year.
4. To make representations to Council on the names of the representatives of the Section to serve on the Committee for the year 1960-61.
5. To discuss the future activities of the Section.
6. To consider any other matters connected with the affairs of the Section.

Nominations to fill the ten vacancies for the Section Committee for 1960-61 are invited. They must be proposed and seconded, and have the consent of the candidate, who must be a Graduate or Student member of the Society. Nominations should be sent to the Hon. Secretary, J. D. Duncan, 8 Carlisle Avenue, St. Albans, Herts.

Members are reminded that the Committee should be representative of as many firms and colleges as possible.

The meeting will be followed by a Film Show. Three new colour films will be shown:—"The Hunter Jet Trainer ", "The Hovercraft" and "High Speed Flight Part 3—Supersonic Flight".

Future Lectures

On Wednesday 9th March, Mr. W. J. Eggington, Special Projects Engineer, Hovercraft Development Ltd., will speak on " The Hovercraft and its Development." The unique characteristics of this type of vehicle make it suitable for a wide variety of fields and the lecturer will be outlining its possibilities from small river hovercraft capable of 30 knots to ocean crossing types.

On Wednesday 6th April Thurstan James will lecture on "Thirty Years of Aeronautical Journalism". Mr. James is Editor of *The Aeroplane and Astronautics*, and his lecture promises to be one of the highlights of the Session.

12th January 1960 was the occasion of an R.Ae.S. Lunch to commemorate the 94th Anniversary of the Society and the 50th of 1910 as the "golden" year of British Aviation. Having outlined 40 years of Branch history in the JOURNAL *for January, it seems appropriate to follow with a brief account of the* BRANCH COMMITTEE *and* BRANCH CONFERENCE.

A REVIEW OF statistics has shown that 28 per cent of Society Members belong to a Branch, and we lamented this surprising and, as we thought, disappointing proportion. However, we find that Society Members do form 35 per cent of Branch Membership and a little further research reveals that in 1944 this was only 10 per cent.

So while we feel that the 28 per cent is still something that should engage the attention of Secretaries, it is a great step forward from 16 years ago, and in that time there has been a great reduction in the size of the Aircraft Industry. This should be a matter for some satisfaction to the Branches, but it is not entirely coincidental that the first Branches Committee was held in 1944.

1944—the end of the War was in sight, and the time had come to take stock and to plan for the future. Four people were present at that first Meeting—Major B. W. Shilson (later to be Chairman), Mr. E. J. Archbold, Mr. A. E. Russell and the Secretary, Captain Pritchard. (Three others were unable to attend.)

Finance was an important topic, with the recommendation that the Society should pay the subscription of the Society Member to his Branch. The Society was also concerned as to what happened to JOURNALS sent to Branches, and that Chairmen should not be elected as figureheads! But the Committee lacked precise information about the Branches, and decided this was first priority!

A month later the replies had been received to their Questionnaire and now, fully armed with facts, the Committee was equipped to attack the future. (We must recall that it was 1944, and the country was still in a Churchillian frame of mind.) At their second Meeting, and among other recommendations which govern our present activities, was the important one that an annual Conference of Chairmen and Secretaries be held at Society Headquarters, with the President in the Chair.

There were 11 Branches, and the Committee was satisfied that, the field being well covered, only one or two more would be required. The U.K. total is now 28, so their feat of alms was better than they knew . . . .

A short-lived suggestion was to hold Branch Committee Meetings at a Branch but one was so held, at Derby, in June 1946. Some points are worth considering even at this later day and age:—

> Press Liaison Officer be appointed by every Branch.
> Local A.T.C. Groups be encouraged to join Branches.
> Members of local flying clubs be encouraged to join.

It was agreed that production of a Branches Journal was of highest priority. This last item was perhaps a little ambitious, but the point was made and, if this page suffices, carried into effect. It took 14 years, but it is done.

Chairmen of the Branches Committee have been Major B. W. Shilson (1944-46), Mr. N. E. Rowe (1946-55, and who during this time instituted the Medal Competition that bears his name), Mr. Handel Davies (1955-58), Mr. S. Scott-Hall (1958-59) and from 1959 the Society's Secretary, Dr. A. M. Ballantyne. As a guide to those who will now be provoked to activity by this Page, the present Committee consists of Messrs. Bendall, Frise, Howarth, Kirk, Rosenthal, Roxburgh, Wansbrough-White, Dr. Moult and S/Ldr. Holden.

The first Branches Conference, with Mr. N. E. Rowe in the Chair, was convened in London in May 1947. It was quickly decided that a full Conference should be held twice a year, instead of annually as the Branch Committee had originally recommended. (So as a present, and rough, measure of progress, there are twice as many Conferences as envisaged, more than double the number of Branches and Members as in 1944, and the Society's Member proportion is threefold. A good beginning.)

Subscriptions—Branch, and Society to Branch—always a subject to enliven the most torpid of Conferences, engaged their attention; but while much has been said and written on this subject, we would observe one engaging aspect. Most Branch subscriptions are unchanged at 5s. with free entry for Society Members. If we go back to the first current Branch as formed in 1925, the decline in unit money values as compared with 1960 is of the order of 2½. So the Branch Member is getting a better product (presumably) for less than half the original cost; alternatively, the Society Member in a Branch is being given, comparatively, a 12s. 6d. subscription for nothing. That he has already paid (or is about to pay) a subscription to the R.Ae.S. is no concern of this Page. But on further thought, it could be.

Committee and Conference have become the focus and forum of our collective activity, but with a very happy relationship with Branch Committees who enjoy an autonomous freedom which, with their power to recruit a wholly local membership, gives an opportunity not normally offered to other bodies.

The Conference has become the "personal" contact between Society and Branch and while circulars, letters, posters, and even telephone calls have their important function, it is the human communication that can achieve so much more. Sir Arnold Hall appealed to the Conference for help with the new Lecture Hall, and the response must have been much greater than would have been achieved by the printed word. Help is still required, but the part played by the Branches in the Society has a recognition in the Town and City Crests that will appear as part of the decorations of the new Lecture Hall. The comments of Council in 1919 that "the Aeronautical Society could not fully attain its objects by holding all its functions and lectures in London" were indeed sound.

All Branch Conferences have been held at No. 4 Hamilton Place up to last year—that is, 1947 to 1959. In April 1959, the first Conference was held away from London and was at Bristol, since when it has been decided to hold the Spring Conference at a Branch, and the Autumn Conference in London. We now look forward to meeting at Brough in April. Not only are these "away" Conferences a business occasion, but also a personal one—more so, in fact, as the visiting delegates stay as personal guests of Branch Members.

Looking back, it may seem that developments in the Branches arising from the Committee and Conference have taken a long time to mature. But our short reviews have shown the great progress made since 1944, and in the Branches themselves since 1919. And as we have just celebrated our 94th Anniversary, we may justly remember that the Aeronautical Society was the only learned body to study its Science before that Science was an accomplished fact. According to some of the best Scientists of 94 years ago, and later, the whole thing was impossible, at best improbable. But as we all know, miracles take a little longer . . . .—G.W-W.

THE LIBRARY

Reviews

AIRCRAFT AND MISSILES. *D. M. Desoutter. Faber and Faber, London, 1959. 213 pp. Illustrated. 36s.*

The sub-title, "What they are, what they do and how they work" confirms that the author's intention is to cover the whole field. A previous book by Mr. Desoutter, *All About Aircraft* did the same but the revised version is twice the size and much glossier.

"The surprising expansion that has occurred in the U.S.A. since the end of the Second World War in aviation for private and business use, must be the forerunner of similar developments elsewhere," considers the author. At a time when the newspapers are full of stories of the contraction of the Aircraft Industry and when private flying in Britain is almost dead, this optimism itself seems to me surprising. There will, nevertheless, be many for whom this book paints an informative picture of the present state of knowledge in aviation.

The whole problem in writing such a book is one of selection. Among the chapter topics are: the air; aeroplane flight; at the speed of sound and beyond; propulsion; fuels; structures and materials; equipment; rotating wings; VTOL and STOL; missiles; history; medical aspects; research and records. Basic principles and developments of them are well described—even the Wallis polymorphous aerodyne is drawn and discussed—but the author gives too many pages, I think, to descriptions of particular engines. Twenty-two gas turbines each have a page and, like Jane's, this part of the book will date quickly.

In writing for the general reader, the known facts cannot be stated completely, but what is given must be accurate. Mr. Desoutter's book will not seriously mislead any reader but there are some doubtful statements on aerodynamics. Lift "is simply a force approximately (*sic*) at right angles to the air stream" (p. 11) and "centre of pressure is . . . . usually a line . . . ." will confuse many who read the chapter on Aeroplane Flight. I would quarrel, too, with starting this chapter by talking about stability. Stability is a difficult concept and cannot be considered until equilibrium has been understood. First must come details of the forces and moments on the aircraft and the methods by which the pilot can trim their resultants to zero. Then, only, can the effects of a disturbance (*i.e.* stability) be discussed. A surprising statement about trim is made on p. 13 where we are told that "the elevator is not used to maintain the correct attitude . . ." but that "the angle of incidence of the whole tailplane on the fuselage is adjusted . . ." The general reader should be assured that trim is still attainable on the majority of aeroplanes flying today.

We are told that induced drag can be reduced by "extending the wings well out, tapering them away to narrow points. The result is that there is virtually very little tip left." I was reminded of a privately financed, wind tunnel test I conducted at the R.A.E. before the war on a model which had the tips tapered to sharp, swept-back points. The inventor was deeply disappointed when the induced drag was found to be still existent.

These technical points are, however, not too important in a general book such as this. The illustrations throughout are excellent and the text very readable. The chapter on the history of flight is of special interest but a list of Important Dates in Aviation always provokes argument. Was 1933 so eventful that it merits seven entries while nothing worth recalling happened in 1945-8 and since 1953? A height record of May 1958 is mentioned elsewhere but the chapter on space has no mention of the sputniks.

This handsome addition to many libraries will do much to inform those who are specialists in but one subject or in none.—A. H. YATES.

DICTIONARY OF AERONAUTICAL ENGINEERING. *J. L. Nayler (Editor). George Newnes, London, 1959. Illustrated. 318 pp. 30s.*

The number of new (and more or less complicated) languages in the world has been increasing at gathering speed during the first half of the twentieth century. In the past two decades glossaries have been prepared in aeronautics, chemistry, nuclear physics, electricity, space projects and what have you, to explain their jargonic languages to those who have forgotten their mother tongue.

But these glossaries do not explain to the man in the street what is happening in the exciting new worlds of science and engineering. The majority of people, who have different intellectual standards, will never become scientists or engineers, but will demand clearer explanations of what is happening in, and to, their world. The dangers of ignorance are greater than those of guided missiles.

Few have seen the birth of so many new words in aeronautical engineering as the editor of this dictionary, who was for so many years the Secretary of the Aeronautical Research Council. The publishers were fortunate in their choice of editor, but less fortunate in not planning for a wider scope and a longer time of preparation. It is no derogation of what Mr. Nayler has achieved to say that the compilation of a twentieth century dictionary is no longer a Johnsonian task.

Mr. Nayler admits that "choice of clear and concise definitions is always a difficult task," and acknowledges his indebtedness to the compilers of aeronautical and other glossaries. But glossaries and dictionaries serve different ends, and taken by and large the *explanations* of a dictionary are simpler than those of a glossary, clearer, and often more concise.

Mr. Nayler has done a valiant job which can be properly praised and captiously criticised equally well, depending upon the use to which the dictionary is put. Primarily the reviewer feels that a lesser reliance could well be placed on glossary definitions and more upon the methods of a modern dictionary to explain what is meant.

Aeronautical engineering covers too wide a field for any one person engaged in it to be *au fait* with the babel of terms used by his fellow travellers (technically speaking!). Sputniks, cavity resonators, cosecant-squared beams, Knudsen numbers, double-base propellants and zero readers . . . . terms, phrases, abbreviations and all, are to be found in the present dictionary, and to be heard at an aeronautical cocktail party. The time is long overdue for more simplification.

Sometimes this super-accuracy is long-winded polysyllabic unintelligibility, and makes one feel like throwing a mixture of sand and clay baked in the shape of a rectangular parallelepiped, or, to quote Mr. Punch, "'Eave 'arf a brick" at them.

But here is the start of the dictionary of the new age. Did not Horace, two thousand years ago, write (in Roscommon's version)

" Men ever had, and ever will have, leave
To coin new words well suited to the age."

Maybe. But sometimes I wonder whether man's leave is nearly up.

Nevertheless you will find this dictionary worth having for reference, while waiting for the new and considerably enlarged edition which must inevitably be published.—J.L.P.

FUELS AND LUBRICANTS. *Milosh Popovich and Carl Hering. Chapman and Hall, London, 1959. 312 pp. Illustrated. 68s.*

This book covers an absurdly wide field. In under 300 pages it attemps to deal with solid fuels (wood, coal and coke), gaseous fuels, all petroleum fuels from gasoline to residual products, rocket propellants, and nuclear fuels together with chapters on crude oil, petroleum refining, calorimetry, organic chemistry and lubricants. The subject matter is, in consequence, very condensed and the treatment is somewhat uneven.

Most of the products are discussed from the viewpoint of their composition and physico/chemical properties with some information on standard methods of test and their significances. There is little information on their application or their performance.

The chapter on gaseous fuels touches on a multitude of products and includes several tables showing composition or typical analyses. Gasoline has a rather better coverage than is given to the other petroleum products and although the main emphasis is on motor fuel, reference is made to aviation grades in dealing with specification tests. There is a good section on combustion knock and related phenomena and the C.F.R. procedures for the octane rating of aviation fuels (the F3 and F4 methods) are briefly indicated.

Distillate and residual fuels are handled in one chapter of which half is devoted to diesel fuels. A short section on " jet fuels " contains a paragraph or two on the gas turbine engine but the space allotted to this whole subject is too small to do it justice.

The main chapter on lubricating oils opens with some discussion on friction, hydrodynamic and boundary lubrication. This is followed by a good but necessarily condensed treatment of viscosity. As far as petroleum oils are concerned the accent is on I.C. engine oils but no specific mention is made of aviation lubricants. There is little or no reference to oils used for other prime movers or for the many diverse applications in industry. Several types of synthetic lubricant are touched upon but there is only a brief reference to their use for aviation.

The authors in their chapter on rocket propellants pay greater attention to performance characteristics of the fuels than is the case with the more conventional products. They describe both solid and liquid propellants and state that in the U.S.A. the most widely used rocket fuel is jet fuel J.P.4.

For the rest the book is nicely printed on good paper with clear tables and illustrations. Each chapter has a useful list of references, principally to American publications, and a list of problems and questions.

The authors say that the book was prepared mainly for use in a college course. We can, therefore, assume that courses ranging over this immense field exist in the U.S.A. but it is hardly likely that such would be the case in any European place of learning.—D. L. SAMUEL.

INTERNAL STRESSES AND FATIGUE IN METALS. *Edited by G. M. Rassweiler and W. L. Grube. D. van Nostrand, London, 1959. 415 pp. Illustrated. 72s.*

This is a book to be skimmed through rapidly, or the end may not be reached; and the Editors have seen fit to relegate to the very end the valuable piece of advice which was in fact offered to those attending the banquet held at the end of the first day of this Symposium at the General Motors Research Laboratories.

That advice (culled by the way from Wyndham Lewis) was " Spy out what's half there, the page beneath the page. Never demand the integral, never completion: Always the fragmentary, the presage . . . . " Thus encouraged the reader may browse contentedly backwards, cropping the lush verbiage which pushes among the forests of dislocations.

In the index dislocations, with fifty-six mentions, just cede pride of place to the pooled references to internal stress (27) and to fatigue (35). Nor are the two title subjects brought elsewhere into close association, until at the end of Part III the marked influence of internal stress on fatigue resistance is demonstrated most elegantly and convincingly by two members of the home team. This influence, deleterious, if the internal stress be tensile, or beneficial, if it be compressive, scarcely seems to be presaged in what goes before, nor explained in what comes after. There stresses are macro or micro rather than tensile or compressive, and microstresses receive rather more loving attention than their elder brothers.

The work as a whole presents a fairly thorough survey of up-to-date views on the state of internal stress in metals, together with some rather desultory discussion of the bearing of these views on the fatigue problem. This is certainly a looking-glass book only to be understood upon reflection and perhaps even then not without the help of an egregious egghead. Meanwhile one can only trust that the word " stress " receives the extra wages it appears to earn.—H. L. COX.

DESERT SQUADRON. *Victor Houart. Souvenir Press, London, 1959. 167 pp. Illustrated. 16s.*

The Publishers' note about *Desert Squadron* is poetical but misleading and inaccurate. The book itself is an interesting and largely factual account of the activities of Beaufighter Squadrons operating in North Africa and Malta in 1942. One cannot help a sigh of regret that, once again, here is a book on the Second World War covering an interesting aspect of air operations but spoilt by errors of fact, poor proof reading and uninformed publicity. In other words it lacks the sense of authenticity that one gets from a book which is written by a man who had personal experience at the time and of the subject about which he is writing. And yet the Publishers say that the author was a pilot in the Belgian Air Force. How is it then that the following expressions can appear in print " . . . . wing incidence adjusted to take-off," and " Thick black glycol fumes streamed from the wing . . . . "? Glycol " fumes " are pure white and the reference to wing incidence presumably should have been to elevator trim.

Then again, a reference is made to the Beaufighter's armament and mentions " four 20 mm. oerlikons, Hispano type." The Oerlikon 20 mm. gun is one type and the Hispano is another, unhappily for the war effort using different ammunition. The Publishers' introduction on the dust jacket says that the name " Whispering Death " was what the German Tank crews called the Beaufighter. The name in fact came from the Japanese. The author refers

to "an unknown squadron of the R.A.F." and mentions it by its number. It had in fact a distinguished record.

The quotations mentioned are a few of the more obvious mistakes in this book and coupled with such things as the mixing-up of the Beaufort and Beaufighter in one incident and the firing of 220 mm. cannon by Beaufighters, the wrong spelling of Lily Marlene and of Abu Sueir all reduce its value as a historical narrative. Its real value lies in the atmosphere of the desert squadron and the characters of its pilots. These are well described in curious contrast with the historical and technical side of the story which suggests insufficient care in its preparation.—A.S.C.L.

Additions to the Library

Advances in Astronautical Sciences. Proceedings of the 3rd Annual Meeting of the A.A.S. 4 Vols. Norman V. Peterson and Horace Jacobs (*Editors*). Chapman and Hall, London. 1958. Sectional pagination. Illustrated. 80s. per volume. *To be reviewed.*

Aircraft Engines of the World 1959/60. P. H. Wilkinson. Published by the author at 734 15th Street, N.W., Washington, D.C. 1959. 320 pp. No price given. The seventeenth annual volume of this invaluable reference book on aircraft engines. A list of earlier engines no longer described, because of lack of space, is now included, with reference to earlier volumes in which a description appears.

Analysis of Deformation. Volume IV. Waves and Vibrations. K. Swainger. Chapman and Hall, London. 1959. 370 pp. Diagrams. 75s. *To be reviewed.*

Economic Study of Supersonic Transports, An. Prepared for Air Research and Development Command, U.S. Air Force. Planning Research Corporation, New York. 1959. 68 pp. $2.50. An economic study for the period 1960-70 with emphasis on military applications. Three conclusions are reached, including the feasibility of supersonic transport for both military and civil applications and the likelihood of a reasonable commercial market for supersonic transports.

Flugmechanische Aufgabensammlung: Flugleistungen. B. T. Gorostschenko. V.E.B. Verlag, Berlin. 1957. 308 pp. No price given. An interesting book if only for the fact that it is the first to be acquired in the Library from East Berlin.

Foundations of Aerodynamics, Second Edition. A. M. Kuethe and J. D. Schetzer. John Wiley, New York. Chapman and Hall, London. 1959. 446 pp. Illustrated. 94s. First published in 1950 with the aim "to build from first principles a background of sound concepts that may be utilised in the application of aerodynamics to problems in aeronautics and other fields of engineering." Features of the second edition include: a rewritten chapter on energy relations, expanded treatment of one-dimensional compressible flows, material on wings in compressible flow now presented from the viewpoint of the lifting-surface theory, and expanded discussion of compressibility in both laminar and turbulent flow. The new edition contains over 100 more pages than the first.

High-Temperature Metals—their Role in the Technological Future. C. Williams. Philadelphia. A.S.T.M. 1959. 16 pp. 80 cents. The seventh H. W. Gillett Memorial Lecture by a metallurgist with an international reputation.

Introduction to Rocket Technology. V. I. Feodosiev and S. N. Samburoff. Academic Press, New York. 1959. 344 pp. Illustrated. $9.50. *To be reviewed.*

Satellites and Scientific Research. D. King-Hele. Routledge and Kegan Paul, London. 1960. 180 pp. Illustrated. 21s. *To be reviewed.*

Selected Topics on Ballistics. W. C. Nelson (*Editor*). (AGARD No. 32.) Pergamon, London. 1959. 280 pp. Illustrated. 63s. *To be reviewed.*

Study of the Attainable Range of Helicopters, A. A. C. Adler and H. S. Holm. 1958. 45 pp. A reprint of a paper presented to the American Helicopter Society Fifth Annual Western Forum in 1958. The authors are at Cornell Aeronautical Laboratory.

Tentative Guide for Fatigue Testing and the Statistical Analysis of Fatigue Data, A. Philadelphia A.S.T.M. 1958. 80 pp. $3. A.S.T.M. Special Technical Publication 91-A, this is a supplement to the Manual on Fatigue Testing (STP 91).

Reports

AERODYNAMICS

Boundary Layer *see also* Compressible Flow

Stability diagrams for laminar boundary layer flow. R. Timman et al. *N.L.L. T.N. F* 193. *Oct.* 1956.
Stability diagrams for a one-parameter family of boundary layer velocity profiles are given. The method of calculation starts from the asymptotic behaviour of the inviscid differential equation of disturbance. Only one solution in the complete domain of integration is used.—(1.1.1).

Effect of distributed three-dimensional roughness and surface cooling on boundary layer transition and lateral spread of turbulence at supersonic speeds. A. L. Braslow et al. *N.A.S.A. T.N. D*-53. *Oct.* 1959.—(1.1.2.4 × 1.1.3.4 × 1.9.1).

An experimental investigation of the noise generated by the turbulent flow around a rotating cylinder. L. N. Wilson. U.T.I.A. Report 57. *April* 1959.
The near and far field noise from the turbulent boundary layer developed on a rigid wall rotating cylinder has been studied; both smooth and artificially roughened surfaces were used. Drag calculations from hot wire measurements allowed an estimate of the efficiency of the far field radiation.—(1.1.3.1 × 5.6 × 32.2.3).

The development of flow separations on the Avro 707A aircraft: a comparison of wind tunnel and flight based on the measurement of surface pressures. D. G. Hurley et al. *A.R.L. Note A* 173. *May* 1959.
The pressure plotting technique has been used to compare the development of the low speed flow separations on the Avro 707A aircraft with their development on an $\frac{1}{4}$th scale model in the 9 × 7 ft. wind tunnel.—(1.1.4 × 1.8.2.2 × 13.2).

Untersuchungen über den Einfluss von Grenzschichtzäunen auf die aerodynamischen Eigenschaften von Pfeil-und Deltaflugeln. A. Das. D.F.L. Bericht 110. 1959.—(1.1 × 1.10.0.2).

Ein Näherungsverfahren zur Berechnung der ebenen und rotationssymmetrischen turbulenten Grenzschicht mit beliebiger Absaugung oder Ausblasung. W. Pechau. D.F.L. Bericht 117. 1958. (*In German.*)
A method for calculating the characteristic values of the turbulent boundary layer is given, based on an approximate solution of the momentum and energy equations of the boundary layer. The method is applicable for arbitrary continuous distributions of the potential velocity as well as for the velocities of suction or blowing along the contour. The necessary assumptions for the shearing stress at the wall and the turbulent dissipation are taken from the theory of turbulent boundary layer without suction. The calculation not only renders the momentum thick-

ness but also the usual parameters H and $\overline{H}$ the changes of which allow a statement regarding the position of the point of separation. In the special case of the flat plate with homogeneous suction the well-known solution by Schlichting is obtained. Further solutions can be given implicitly for flows with similar profiles of the boundary layer (solution of similarity).—(1.1.8.1).

COMPRESSIBLE FLOW *see also* FLUID DYNAMICS
INTERNAL FLOW
TESTING AND INSTRUMENTS
FLIGHT TESTING

Effect of body perturbations on hypersonic flow over slender power law bodies. H. Mirels and P. R. Thornton. N.A.S.A. T.R. R-45. 1959.
Hypersonic-slender-body theory, in the limit as the free-stream Mach number becomes infinite, is used to find the effect of slightly perturbing the surface of slender two-dimensional and axisymmetric power law bodies. The body perturbations are assumed to have a power law variation (with streamwise distance downstream of the nose of the body). Numerical results are presented for: the effect of boundary layer development on two-dimensional and axisymmetric bodies; the effect of very small angles of attack (on two-dimensional bodies); and the effect of blunting the nose of very slender wedges and cones.—(1.2.3.1).

Some aspects of air-helium simulation and hypersonic approximations. E. S. Love et al. *N.A.S.A. T.N. D-49. Oct.* 1959.
Illustrations of air-helium differences and expressions for simulation which in general form are applicable to any two ideal gases having different ratios of specific heats are presented. Viscous and non-viscous flows are considered.—(1.2.3.1 × 1.1.1.4 × 1.1.3.4).

The use of artificial singularity distributions to find minimum drag for fixed base area in supersonic flow. E. W. Graham and B. J. Beane. Douglas Report SM-23698. Sept. 1959.
The application of the method of artificial singularities to the problem of finding minimum thickness drag in supersonic flow, subject to the constraint of fixed base area, is considered. No further limitations are imposed other than those inherent in linearised theory. A suitable artificial singularity distribution employing sources as well as lift and side-force elements is described. The method is illustrated for the special example of a Mach envelope rim which lies entirely in one plane, the plane being swept with respect to a normal to the free stream direction. For wings or wing-body systems that correspond to the prescribed Mach envelope rim, the minimum value of supersonic wave drag under the restriction of fixed base area is found. Extension of the method to more general cases where the Mach envelope rim does not lie in a single plane is also indicated.—(1.2.3.1).

A two-dimensional theory of the oblique shock intake based on the hodograph method. L. F. Henderson. A.R.L. Report ME 90. March 1959.—(1.2.3.2)

CONTROLS *see also* WINGS AND AEROFOILS

A theoretical study of the ground effect on the jet flap. D. J. Huggett. Univ. Southampton Report U.S.A.A. 112. Sept. 1959.
A theory is developed for a jet flap wing near the ground. Under conditions for which the jet hits the ground, this theory gives, for any jet deflection angle and distance of wing from the ground, the distribution of pressure lift on the wing, the total pressure lift on the wing and the shape of the jet. Results are included for a wide range of jet coefficients with the ground at two different positions. At each ground position two different jet deflection angles are taken. The results of the theory are compared with experiment, and the agreement is discussed.—(1.3.4 × 1.10.1.1).

Investigation of double slotted flaps on a swept-wing transport model. R. L. Naeseth and E. E. Davenport. N.A.S.A. T.N. D-103. Oct. 1959.
The flaps had a chord of 0·33 wing chord and a ratio of vane chord to flap chord of 0·5. Some considerations of design of a double slotted flap are briefly discussed. The Reynolds number was $0{\cdot}9 \times 10^6$.—(1.3.4 × 1.3.7 × 1.8.2.2).

FLUID DYNAMICS *see also* THERMO-AERODYNAMICS
WINGS AND AEROFOILS

The choice of an optimum set of measurements to study atomic recombination in nozzles. K. N. C. Bray and J. P. Appleton. U.S.A.A. Report 120. Nov. 1959.
The accuracy of experiments designed to study the process of atomic recombination in a hypersonic wind tunnel nozzle is investigated. Three types of experiment are considered: (*i*) to determine whether a given flow is closer to the equilibrium or the frozen state; (*ii*) to determine the dissociation fraction in the test section of the nozzle; and (*iii*) to determine the recombination rate constant.—(1.4 × 1.2.3.1 × 1.5.1.4 × 32.1).

Application to fluid dynamics of the theory of reversible heat addition. B. S. Baldwin. N.A.S.A. T.N. D-93. Oct. 1959.
A discussion of the approximations required to relate the equations of Hicks and Shapiro for gas flows with heat addition to the general relations for radiating, reacting gas flows by Hirschfelder, Curtiss and Bird, is given. The theory of reversible heating is applied to underwing heat addition at hypersonic speeds. and the results of a series of exact calculations are given. The effects on aircraft range of several arrangements of external heat addition are presented.—(1.4 × 1.9.3 × 27.4 × 34.1).

Gesetzmassigkeiten der geradlinigen turbulenten Couetteströmung. H. Reichardt. Max-Planck Inst. Mitt. 22. 1959. (*In German.*)—(1.4.2).

INTERNAL FLOW *see also* FLUID DYNAMICS
THERMO-AERODYNAMICS
WINGS AND AEROFOILS
POWER PLANTS

An experimental investigation of a supersonic two-dimensional perforated inlet at a nominal free stream Mach number of 2·5. J. P. C. Clark. U.T.I.A. T.N. 24. Nov. 1958.
A two-dimensional supersonic diffuser in the form of a reversed de Laval nozzle has been tested at a nominal free stream Mach number of 2·5. The resulting bow shock was induced to move into the intake and eventually past the throat by perforating the diffuser walls. Windows in the side walls enabled visual studies of the shock swallowing process to be made and a series of 19 static pressure taps in the diffuser walls provided pressure distributions as a function of perforation and exit areas.—(1.5.1.4 × 1.2.3.2).

LOADS

An analysis of incremental horizontal-tail loads measured on a swept-wing bomber airplane in sideslip maneuvers. W. A. McGowan. N.A.S.A. T.N. D-100. Oct. 1959.
An analysis is presented of incremental horizontal tail loads measured on a swept-wing bomber aeroplane at altitudes to 35,000 ft. and Mach numbers to 0·82. Data from rudder-step, aileron-roll, and steady-sideslip manoeuvres were reduced to give derivatives of the horizontal tail normal force and rolling moment coefficients with respect to sideslip angle and the rate of change of wing-fuselage combination pitching-moment coefficient with sideslip angle. The derivatives were compared with wind tunnel and theoretical values where possible.—(1.6.2 × 1.8.0.2 × 2 × 3.6).

Importance of the variation of drag with lift in minimization of satellite entry acceleration. F. C. Grant. N.A.S.A. T.N. D-120. Oct. 1959.
An acceleration parameter is derived which defines the minimum peak acceleration in terms of a simple integral of the aerodynamic coefficients of the vehicle. Numerical calculations are presented for an entry vehicle with a simplified but realistic complete drag polar.—(1.6.2 × 25.2).

Calculation of aerodynamic forces on slowly oscillating rectangular wings in subsonic flow. A. I. v. d. Vooren and E. M. De Jager. N.L.L. Report T.N. F-192. Oct. 1956.
A method is presented for the calculation of the aerodynamic forces on a slowly oscillating aerofoil, which is essentially a lifting surface theory which takes into account the unsteady effects due to the wake. Results are given as series containing terms of increasing powers in reduced frequency. The method has been applied to rectangular aerofoils.—(1.6.3 × 2).

PERFORMANCE

Piecemeal solutions in the programming of optimal flight trajectories. P. Cicala. N.A.S.A. T.T. F-3. Oct. 1959.
The general equations that govern the shape of the optimal

flight paths that may be executed in a vertical plane are written out in a form which is especially suited to study of the practical situation wherein the complete trajectory is made up out of piecemeal sections of diverse character.—(1.7×5).

Optimum airplane flight paths. P. Cicala. N.A.S.A. T.T. F-4. Oct. 1959.
The generalised equations are discussed which pertain to an aeroplane executing its flight path in a single vertical plane, under a sequence of stipulations specifying the nature of the local optima which are distinctly different in character along successive portions of this path. The aerodynamic and propulsive characteristics of the aeroplane are allowed to be specified with complete generality.—(1.7×5).

STABILITY AND CONTROL *see also* BOUNDARY LAYER
CONTROLS
LOADS

The airplane as an object of control. V. S. Vedrov et al. *N.A.S.A. T.T. F-5. Oct.* 1959.
The presentation of equations for the perturbed motion of an aeroplane in the form of single-loop block diagrams is considered. A brief analysis is given of the characteristics of the individual links and of their change with changing flight speed and altitude. A derivation of transfer functions for control with elevator, rudder, and aileron is presented, as well as simplified expressions for the transfer functions, depending on the frequency range, which correspond to breaking up the perturbed motion into simple types.—(1.8.0.1).

Investigation at transonic speeds to determine lateral control effectiveness of blowing laterally over surfaces of 30° *and* 45° *swept wings. A. D. Hammond and L. W. McKinney. N.A.S.A. T.N. D-42. Oct.* 1959.
This investigation was made on two semispan wings having quarter-chord-line sweep angles of 30° and 45°; each wing had an aspect ratio of 4, a taper ratio of 0, and an N.A.C.A. 65A004 aerofoil section. The basic data are presented in tabular form and the partial derivatives of the force and moment coefficients with respect to momentum coefficient are presented in graphic form. A limited discussion of the effects of lateral blowing on the rolling moment characteristics is presented.—(1.8.1.2×1.10.2.2).

Low-speed wind-tunnel investigation of a wingless jet VTOL transport model. M. O. McKinney. N.A.S.A. T.N. D-57. Oct. 1959.
The investigation consisted of power-off and power-on wind tunnel tests of the static stability and lift and drag characteristics of a small-scale model representing a wingless turbo-jet powered VTOL transport aeroplane. The model consisted of a fuselage with conventional tail surfaces at the rear and with 12 simulated jet engines near the centre which could be tilted from a horizontal attitude for normal forward flight to a vertical attitude for hovering flight.—(1.8.0.2).

Studies of second- and third-order contactor control systems. I. Flugge-Lotz and H. E. Lindberg. N.A.S.A. T.N. D-107. Oct. 1959.
The response of second- and third-order contactor systems with switching according to the sign of a linear combination of the error and its derivatives is studied. The example for the third-order system is a simplified equation of the pitching motion of a missile whose control surface takes on only two positions, full up or full down.—(1.8.0.1×22.2).

Grundsätzliche Betrachtungen zur Flugregelung. R. Wotschke. D.F.L. Bericht 120. 1958. (*In German.*)—(1.8.0.1×4.3).

THERMO-AERODYNAMICS *see also* BOUNDARY LAYER
FLUID DYNAMICS
MATERIALS

Unsteady stagnation-point heat transfer. E. M. Sparrow. N.A.S.A. T.N. D-77. Oct. 1959.
An analysis is made of the unsteady, forced-convection heat transfer at a stagnation point whose surface temperature varies arbitrarily with time. The flow is steady and laminar. Comparison is made between the unsteady heat transfer results of this analysis and those computed under the assumption of quasi-steady conditions. Numerical results are presented for a Prandtl number of 0·7 (*i.e.* gases).—(1.9.1×1.4×34.3.2).

Experimental investigation of metal temperatures of air-cooled airfoil leading edges at subsonic flow and gas temperatures up to 2780°*F. F. S. Stepka and H. T. Richards. N.A.S.A. T.N. D-127. Nov.* 1959.
Three configurations of internally cooled aerofoil leading edges were investigated to determine their cooling characteristics and the effect of afterbody temperature (afterbody cooled independently of leading edge) on leading edge temperature. A method of correlating the average leading edge metal temperatures is presented.—(1.9.1×34.3×1.5.3).

Use of a theoretical flow model to correlate data for film cooling or heating an adiabatic wall by tangential injection of gases of different fluid properties. J. E. Hatch and S. S. Papell. N.A.S.A. T.N. D-130. Nov. 1959.
An equation is derived, by use of a simplified theoretical flow model, that predicts the temperature of a film-cooled wall within 5 per cent for a range of cooling effectiveness from approximately 0·2 to 1·0. Data covering a wide range of the variables (main gas stream velocity and temperature, velocity ratio, and coolant slot height) were used in the correlation. Both helium and air were used as the coolant gas.—(1.9.1×34.3×27.3).

Measurements of heat transfer and friction coefficients for helium flowing in a tube at surface temperatures up to 5900°*R. M. F. Taylor and T. A. Kirchgessner. N.A.S.A. T.N. D-133. Oct.* 1959.
Measurements are made with helium flowing through electrically heated smooth tubes for the following range of conditions: average surface temperature from 1457° to 4533°R. Reynolds number from 3230 to 60,000, heat flux up to 345,000 Btu per hour per square foot of heat transfer area, and exit Mach number to 1·0.—(1.9.1×34.3).

WINGS AND AEROFOILS *see also* BOUNDARY LAYER
CONTROLS
STABILITY AND CONTROL
FLIGHT TESTING
HYDRODYNAMICS

Effects of interaction between boundary layers and external stream and of incidence on boundary layer drag at supersonic speeds. A. D. Young and S. Kirkby. C.P. 451. 1959.
This paper completes a series dealing with the determination of the boundary layer drag of biconvex wing sections at supersonic speeds with zero heat transfer for a range of thickness-chord ratio mainstream Mach number, Reynolds number and transition position. Previous results have been extended and improved by allowing for the interaction of boundary layer and external stream, insofar as the resulting changes in the external pressure distribution modify the skin friction distribution. Calculations have also been made of the effect of incidence on the boundary layer drag of flat plate. The discussion includes an analysis in physical terms of the effects on skin friction and boundary layer pressure drag distributions of main parameters investigated and in particular of the changes that accompany increase in Mach number.—(1.10.1.1×1.1.0.4).

Low speed tunnel measurements of the ground effect on a $\frac{1}{4}$*th scale model of the Swift. M. N. Wood and W. J. G. Trebble. C.P.* 458. 1959.
Low speed tunnel tests have been made on a $\frac{1}{4}$th scale model of the four-gun Swift to collect information on the effect of ground on swept-winged aircraft. Lift, drag and pitching moment have been measured with the model in free stream and also at two distances from the ground board, the nearer position of the mean quarter chord point being 0·42 mean chords from the board. Two tailplane positions and various flap configurations have been tested.—(1.10.2.2×1.8.2.2).

Wind tunnel tests of a semispan wing with a fan rotating in the plane of the wing. D. H. Hickey and D. R. Ellis. N.A.S.A. T.N. D-88. Oct. 1959.
An investigation was conducted to determine the aerodynamic characteristics of an aspect ratio 4 wing model with a fan rotating in the plane of the wing. Force, pressure, and power measurements were obtained with fan-duct inlet and exit vanes. These data were obtained for tip speed ratios from 0·1 to 0·5.—(1.10.2.2×29.1×1.5.1).

Low-speed experiments on the wake characteristics of flat plates normal to an air stream. R. Fail et al. *R. & M.* 3120. 1959.—(1.10.2.2×1.3.4).

Trim drag at supersonic speeds of various delta-planform configurations. M. E. Graham and B. M. Ryan. Douglas Report SM-23635. July 1959.
The drag due to lift and the maximum life-to-drag ratio at supersonic speeds of zero thickness, trimmed, statically stable (*i*) delta-wing-plus-tail (*ii*) delta-wing-plus-canard, and (*iii*) delta-wing-alone configurations are studied with the aid of linear theory. These configurations do not include a body.—(1.10.1.2 × 1.8.2.1).

Tragflügeltheorie bei Unterschallgeschwindigkeit. K. Gersten. D.F.L. Bericht 115. 1958.
A broad survey is given about recent work of wing theory for incompressible stationary flow. As mathematical foundations have already been summarised by J. Weissinger on occasion of the Fluid Mechanics Meeting at Göttingen, 1955, the extensions of well-known methods and comparison between theory and experiments are especially treated. Problems which are more or less unsolved are emphasised, *e.g.* ring aerofoil, jet-flap and non-linear theories of wings.—(1.10.0.2 × 1.4).

Aerodynamische Eigenschaften von Pfeil-und Deltaflügeln in Bodennähe. F. Thomas. D.F.L. Bericht 116. 1958. (*In German.*)
A method based on the extended lifting line theory is given which allows to calculate the lift distribution near the ground for aerofoils of arbitrary plan form, particularly swept-back and delta wings. The ground effect is taken into account by the reflection method. The velocities induced by the reflected aerofoil at the actual aerofoil considered are calculated in accordance with a method given by K. Gersten.—(1.10.1.2 × 1.8.2.1).

HELICOPTER AERODYNAMICS

The effects of various combinations of damping and control power on helicopter handling qualities during both instrument and visual flight. S. Salmirs and R. J. Tapscott. N.A.S.A. T.N. D-58. Oct. 1959.
Summary charts are presented which show the effects of both damping and control power on handling qualities. These charts are expected to be useful in estimating desirable characteristics for other helicopters and VTOL aircraft.—(1.11.2 × 5).

TESTING AND INSTRUMENTS *see also* FLIGHT TESTING

Shock speed and running time measurements in the N.P.L. hypersonic shock tunnel. B. D. Henshall. C.P. 443. 1959.
Resistance thermometers have been used in the measurement of shock speeds and running times in the N.P.L. Hypersonic Shock Tunnel. From an analysis of the first 600 runs, a method has been devised which enables the gasdynamic operation of the shock tunnel to be checked and any irregularities discovered.—(1.12.1.3 × 1.2.3.2).

Wind tunnel calibrations of a combined pitot-static tube, vane-type flow-direction transmitter and stagnation-temperature element at Mach numbers from 0·60 to 2·87. N. R. Richardson and A. O. Pearson. N.A.S.A. T.N. D-122. Oct. 1959.
Error curves for Pitot static pressure measurements and flow-direction vane correction curves for a range of angles of attack and sideslip are presented.—(1.12.5 × 13).

AEROELASTICITY

See AERODYNAMICS—LOADS

AIRCRAFT

See AERODYNAMICS—LOADS
FLIGHT TESTING

DESIGN AND CONSTRUCTION

See AERODYNAMICS—STABILITY AND CONTROL

AIRCRAFT OPERATION

See also AERODYNAMICS—BOUNDARY LAYER
PERFORMANCE
HELICOPTER AERODYNAMICS
HYDRODYNAMICS
STRUCTURES—LOADS

Some recent developments in jet noise research. E. J. Richards and J. E. Ff. Williams. Univ. Southampton Report U.S.A.A. 118. *Aug.* 1959.
Recent work on the identification and understanding of the noise source regions in a turbulent jet is dealt with. Space time correlation techniques as used in the investigation of convected fields of flow are discussed. Recent work concerned with the velocity of convection of turbulent fields is summarised, and some interesting aspects of research into boundary layer noise are discussed.—(5.6).

Effect of forward velocity on sound-pressure level in the near noise field of a moving jet. J. C. Faken and H. R. Mull. N.A.S.A. T.N. D-61. Oct. 1959.
An inflight investigation of the near noise field along the boundary of an aircraft-mounted jet engine was conducted over a flight Mach number range of 0·35 to 0·70 at altitudes of 10,000, 20,000 and 30,000 ft., at 2 and 3 nozzle exit diameters downstream of the jet exit.—(5.6 × 27.1.1).

Uber den Lärm von Strahlantrieben und seine Verminderung. F. Staab. D.F.L. Bericht 121. 1958. (*In German.*)—(5.6 × 27.1.1).

EXTRA-ATMOSPHERIC TECHNOLOGY

See also MISSILES

Departure trajectories for interplanetary vehicles. W. E. Moeckel. N.A.S.A. T.N. D-80. Nov. 1959.
General expressions are derived for the magnitude and direction of the launching velocity needed to reach another planet from any point on the Earth's surface. The effect of the inclination of the orbital plane of the destination planet is considered, as well as the effect of departure date and selected trajectory. A procedure is given for determining optimum time of day for launching from any latitude to obtain maximum benefit of the Earth's rotation. Results of the analysis are illustrated for typical Earth-Venus trajectories.—(8.2 × 25.2 × 27.3).

Methods and velocity requirements for the rendezvous of satellites in circumplanetary orbits. W. E. Brunk and R. J. Flaherty. N.A.S.A. T.N. D-81. Oct. 1959.
In the future of space flight there will be occasions when it is necessary to perform a rendezvous between two satellites in orbit around a planet. For a spherical planet methods of rendezvous are considered in which the total velocity required is close to a minimum. Since some of the planets are not spherical, the assumption of a spherical planet does not always apply. For the case of the Earth, the effects of oblateness on rendezvous are considered.—(8.2 × 26 × 27.3).

Predicted characteristics of an inflatable aluminumized-plastic spherical earth satellite with regard to temperature, visibility, reflection of radar waves, and protection from ultraviolet radiation. G. P. Wood and A. F. Carter. N.A.S.A. T.N. D-115. Oct. 1959.
An investigation was made to predict whether a hollow aluminised-plastic sphere in a terrestrial orbit at an altitude of about 1,000 miles would be easily visible to the naked eye, would be a good reflector of radar waves, would be protected from deterioration of the plastic by ultraviolet radiation, and would assume acceptable extremes of temperature.—(8 × 21.2.2 × 21.3.3).

Trajectories with constant tangential thrust in central gravitational fields. W. E. Moeckel. N.A.S.A. T.R. R-53. 1959.
Trajectories followed by vehicles propelled by a constant thrust directed parallel to the velocity vector were calculated in non-dimensional form for a range of initial thrust/weight ratios from 10 to 10^{-4} and for a range of jet velocities from those attainable with chemical rockets to infinity. Trajectories are presented both for the departure outward from, and the inward return to, any circular orbit. Results are given in the form of curves of radial distance, energy per unit mass (hyperbolic velocity), trajectory inclination, and velocity and angular distance as functions of time. Utilisation of these charts to estimate weight requirements for interplanetary missions is discussed.—(8 × 25.2 × 27.3).

ELECTRONICS

Drahtlose Fernübertragung von Messwerten bei der Erprobung von Flugzeugen. A. Becker. D.F.L. Bericht 118. 1958. (*In German.*)
The methods which are generally used for telemetric communication are briefly described.—(11 × 13.3).

FLIGHT TESTING

See also AERODYNAMICS—BOUNDARY LAYER
TESTING AND INSTRUMENTS
ELECTRONICS

Flight measurements of the drag of an aircraft fitted with a rear fuselage fairing designed to reduce the transonic drag. D. R. Andrews et al. *C.P.* 459. 1959.
Tests have been made to determine what reduction in drag could be achieved by fitting a fairing to the rear fuselage of a Hawker Hunter aircraft. This fairing was designed to control the shock wave movements in the wing body junction and so reduce the transonic drag rise. Area distributions at $M = 1{\cdot}08$ were also improved to some extent.—(13.3 × 1.2.2 × 3.6).

Flight investigation of the lift and drag characteristics of a swept-wing, multijet, transport-type airplane. R. Tambor. N.A.S.A. T.N. D-30. *Nov.* 1959.
The lift and drag characteristics of a Boeing KC-135 are presented for the clean configuration in the drag-rise Mach number region and for the low speed landing configurations. The effects of aeroplane weight and flap deflection on lift drag ratio and landing and take-off speeds are also shown.—(13.3 × 1.10.3.4 × 1.12.2 × 3.6.).

Verfahren zur Flugbahnvermessung. O. Weber. D.F.L. Bericht 119. 1958. (*In German.*)
The essential characteristics of optical and electronic methods and instrumentation for measuring the flight paths from the ground are summarised. Several possibilities for improving the instruments and for simplifying and speeding up the evaluation of the test values are discussed.—(13.3).

FUELS AND LUBRICANTS

See also POWER PLANTS

A one-dimensional theory of liquid-fuel rocket combustion. D. B. Spalding. C.P. 445. 1959.
The system considered is an ideal rocket motor in which all properties depend only on distance from the injector face and droplets have uniform diameter on entry. Processes considered are droplet drag, vaporisation and chemical reaction. Equations are derived, integration of which leads to a prediction of the minimum length of rocket motor.—(14.3 × 34.1.1 × 27.3).

A one-dimensional theory of liquid-fuel rocket combustion. Part II. The influence of chemical reaction. J. Adler. C.P. 446. 1959.
The differential equations, resulting from the one-dimensional liquid-fuel rocket combustion Model II of Spalding, have been integrated and temperature and velocity profiles for the fuel droplets are derived. A simple approximate procedure for solving the equations is also given which gives good results when compared with exact integration.—(14.3 × 34.1.1 × 27.3).

Theory of the burning of mono-propellant droplets. D. B. Spalding and V. K. Jain. C.P. 447. 1959.
Formulae are derived for the burning rate and time of mono-propellant droplets suspended in an atmosphere of their own decomposition products. The liquid temperature is assumed constant and the activation energy of the reaction is supposed high. Some experimental data are cited in qualitative support of the theory.—(14.3 × 34.1.1).

The solution of an eigenvalue problem (rate of evaporation and decomposition of a droplet of an ozone-oxygen mixture) by means of analogue and digital computers. R. Sandri. N.R.C. Report MP-15. *Aug.* 1959.
The rate of evaporation and decomposition of a droplet of a 50-50 mole per cent mixture of liquid ozone and oxygen in a hot oxygen atmosphere at 20 atmospheres pressure was computed for different sizes of the droplet radius.—(14.3 × 34.1.2 × 22.1).

HYDRODYNAMICS

The hydrodynamic characteristics of a submerged lifting surface having a shape suitable for hydro-ski application. V. L. Vaughan. N.A.S.A. T.N. D-51. *Oct.* 1959.
An aspect ratio 0·25 hydro-ski model was investigated to determine the lift, drag, and pitching moment about the trailing edge at depths of submersion of 1·0, 1·5, 3·0 and 6·0 inches over a range of angles of attack from −2° to 20° and at speeds up to approximately 85 ft./sec. Comparisons between the data from this investigation and data on a rectangular modified flat plate having the same aspect ratio are presented. Discussions and comparisons of cavitation and ventilation are presented in some detail.—(17.2 × 1.10.2.2).

Water-landing impact accelerations for three models of reentry capsules. V. L. Vaughan. N.A.S.A. T.N. D-145. *Oct.* 1959.
Three conical models were tested to determine the rigid-body impact accelerations for nominal flight path angles of 90° and 65°, a range of contact attitudes of −30° to 30°, and a range of full scale vertical contact velocity from 10 to 45 ft./sec. Accelerations of the models at impact were measured along the roll and yaw axes.—(17 × 33.1.2).

Rough-water ditching investigation of a model of a jet transport with the landing gear extended and with various ditching aids. W. C. Thompson. N.A.S.A. T.N. D-101. *Oct.* 1959.
A dynamic model with certain portions approximately scale strength was used to determine the probable ditching behaviour and damage. The ditching aids included several hydro-ski and hydrofoil arrangements. Data were obtained from visual observations, acceleration records, and motion pictures.—(17.2 × 5.3).

MATERIALS

See also EXTRA-ATMOSPHERIC TECHNOLOGY
THERMODYNAMICS
FATIGUE
STRUCTURES—LOADS

Investigation of ignition temperatures of solid metals. W. C. Reynolds. N.A.S.A. T.N. D-182. *Oct.* 1959.
The ignition temperature of a solid metal is related through a thermal definition of ignition to the rate of oxidation and to the radiation and convection heat transfer parameters. The mechanisms of oxidation are reviewed and the factors which influence ignition temperatures are discussed.—(21.2 × 34.1.1 × 1.9.1).

Étude expérimentale de la déformation a la surface autour et a l'intérieur de l'empreinte Brinell. A. Popoff. O.N.E.R.A. N.T. 55. 1959.—(21.6.1).

MATHEMATICS

See AERODYNAMICS—STABILITY AND CONTROL
FUELS AND LUBRICANTS

MISSILES

See also AERODYNAMICS—LOADS
EXTRA-ATMOSPHERIC TECHNOLOGY

Optimum trajectory problems: some special cases. E. W. Graham and B. J. Beane. Douglas Report SM-23687. *Sept.* 1959.
The transfer of a rocket vehicle from one point to another with minimum fuel expenditure is studied. The velocity vectors at the terminal points and the time for transfer are specified. It is assumed that the rocket vehicle is operated in a gravitational field without atmospheric resistance. A moving co-ordinate system is used, and the required terminal velocity vectors are specified in this system. Also the variation of gravitational force with position produces a perturbation force field in this co-ordinate system. Two types of analysis are considered. The first is restricted to short transfer times, but applies to arbitrary gravitational fields. The second is restricted to transfer between points on a radial line in a central force field, but the time for transfer can be large if the terminal points are properly spaced. —(25.2 × 8).

NAVIGATION

See EXTRA-ATMOSPHERIC TECHNOLOGY

POWER PLANTS

See also AERODYNAMICS—FLUID DYNAMICS
THERMO-AERODYNAMICS
AIRCRAFT OPERATION
EXTRA-ATMOSPHERIC TECHNOLOGY
FUELS AND LUBRICANTS
FATIGUE

Control of combustion-chamber pressure and oxidant-fuel ratio for a regeneratively cooled hydrogen-fluorine rocket engine. E. W. Otto and R. A. Flage. N.A.S.A. T.N. D-82. Nov. 1959.
The design of a chamber pressure and mixture ratio control system employing electrohydraulically actuated propellant control valves, Venturi and strain-gauge flow-measuring systems, and a strain-gauge combustion chamber pressure measuring system is presented. The component and control loop dynamics are analysed, and the performance of the system on the engine is presented. Construction details of the system are given.—(27.3).

Comparison of hydrazine-nitrogen tetroxide and hydrazine-chlorine trifluoride in small-scale rocket chambers. R. J. Rollbuhler and W. A. Tomazic. N.A.S.A. T.N. D-131. Oct. 1959.
Experimental characteristic exhaust velocity was obtained for both combinations using four basic types of injectors—triplet, swirl cup, shower head, and like-on-like. Tests were made in a 300 lb. thrust uncooled rocket engine at 300 lb./sq. in. abs. The propellant mixture was varied.—(27.3×14.3×34.1.1).

Brennkammer für Kleingasturbinen bei Betrieb mit verschiedenen Brennstoffen. O. Lutz et al. *D.F.L. Bericht* 84. 1959. (*In German.*)—(27.1).

Vergleich von Gleichdruck-und Verpuffungsgasturbinen. K. Graf. Forsch: W und V.M. Nordrhein-Westfalen. Nr. 546. 1958. —(27.1.2×1.5.4.3).

PROPELLERS

See AERODYNAMICS—WINGS AND AEROFOILS

FATIGUE

Thermal fatigue of ductile materials. III—Behavior of crucible 422 steel. F. J. Clauss. N.A.S.A. T.N. D-69. Oct. 1959.
Behaviour of Crucible 422 steel in thermal fatigue and the effect of constrained and free thermal cycling on the subsequent stress rupture life were studied. Specimens were alternately heated and cooled through a maximum cycle temperature from 1000° to 1500°F and a minimum cycle temperature of 200°F, both with and without constraint. The number of cycles to failure, changes in hardness and microstructure, and stress rupture properties were studied as a function of the conditions of thermal cycling. Changes in stress rupture behaviour were judged on the basis of the life at 1100°F and 46,000 psi—(31.2.2.2.1.8×21.2.1×27.1).

Effect of rest periods on fatigue of high-purity aluminum. J. W. Berry et al. *N.A.S.A. Memo* 11-21-58*W. T.I.L.* 6504. *Dec.* 1958.
Tests on aluminium specimens were performed under two conditions. In one the specimens were tested at elevated temperatures and the rest periods were given at room temperature; in the second the specimens were tested at room temperature and the rest periods were given at elevated temperature.—(31.2.2.3.1.8×21.2.2).

SCIENCE—GENERAL

See AERODYNAMICS—BOUNDARY LAYER
FLUID DYNAMICS

STRUCTURES

LOADS *see also* HYDRODYNAMICS

Investigation of high-speed impact: regions of impact and impact at oblique angles. J. L. Summers. N.A.S.A. T.N. D-94. Oct. 1959.
Small metal spheres of various densities were fired into copper and lead targets at impact velocities up to 11,000 ft./sec. The regions or types of impact are described. A correlation of penetration for normal and oblique impact is presented.—(33.1.2×21.2).

Limited investigation of crushable structures for acceleration protection of occupants of vehicles at low impact speeds. T. C. O'Bryan and H. G. Hatch. N.A.S.A. T.N. D-158. Oct. 1959.
A limited investigation has been made to determine the characteristics of three materials to see how they can be applied for human protection against accelerations encountered at low impact speeds.—(33.1.2×5.3×21.2.3×21.3.3).

THEORY AND ANALYSIS

The phenomenon of change in buckle pattern in elastic structures. M. Stein. N.A.S.A. T.R. R-39. 1959.
A model is analysed which exhibits the important properties associated with change in buckle pattern of plates. The analysis includes a rigorous study of stability in its various modes. A discussion of how the present results may be applied to plates and other elastic structures is given.—(33.2.4.2×33.2.4.5×33.2.4.6×33.2.4.11).

Loads and deformations of buckled rectangular plates. M. Stein. N.A.S.A. T.R. R-40. 1959.
The non-linear large deflection equations of von Kármán for plates are converted into a set of linear equations by expanding the displacements into a power series in terms of an arbitrary parameter. The post buckling behaviour of simply-supported rectangular plates subjected to longitudinal compression and to a uniform temperature rise is investigated in detail by solving the first few of the equations. Experimental data are presented for the compression problem. Comparisons are made for total shortening and local strains and deflections which indicate good agreement between experiment and theory.—(33.2.4.5.1×33.2.4.6.1).

Minimum-weight analysis of symmetrical-multiweb-beam structures subjected to thermal stress. R. R. McWithey. N.A.S.A. T.N. D-104. Oct. 1959.
A study to determine beams of optimum weight based upon buckling and yielding stress criteria is presented. Curves of minimum structural weight and optimum values of the beam parameters are shown as a function of the bending moment for various temperature differences between skin and web.—(33.2.4.1.9×33.4.1).

Investigations of creep behavior of structural joints under cyclic loads and temperatures. L. Mordfin et al. *N.A.S.A. T.N. D-181. Oct.* 1959.
Eighty-two structural joint specimens were tested to evaluate the effects of cyclic loads and cyclic temperatures on creep and rupture. The specimens included riveted joints of 2024-T3 clad aluminium alloy, and riveted and spot-welded joints of 17-7 PH (TH 1050) stainless steel.—(33.2.4.13.10×33.2.4.13.9×21.2).

TESTING

Different applications of photoelastic layers in the structural field. G. Golubovic. R.A.E. Trans. 838. *Sept.* 1959.
After a brief discussion in the theoretical bases of photoelasticity testing methods, an account of two commercially available machines for testing is given. These operate on an actual specimen to which is attached a layer of photoelastic material, rather than on a model made in suitable material as in the classical methods. A number of examples of the use of the new method and machines is given.—(33.3.1).

WEIGHT ANALYSIS AND CONTROL *see* THEORY AND ANALYSIS

THERMODYNAMICS

See also AERODYNAMICS—FLUID DYNAMICS
THERMO-AERODYNAMICS
FUELS AND LUBRICANTS
POWER PLANTS

Theoretical and experimental investigation of heat conduction in air, including effects of oxygen dissociation. C. F. Hansen et al. *N.A.S.A. T.R. R-27.* 1959.
Solutions are presented for the conduction of heat through a semi-infinite gas medium having a uniform initial temperature and a constant boundary temperature. The coefficients of thermal conductivity and diffusivity are treated as variables, and the solutions are extended to the case of air at temperatures where oxygen dissociation occurs. These solutions are used together with shock-tube measurements to evaluate the integral of thermal conductivity for air as a function of temperature.—(34.3.3×1.9.1).